S P E C I A L   A R T I C L E

Role of Magnetic Resonance Imaging in the Management of Patients With Multiple Myeloma: A Consensus Statement

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See accompanying editorial on page 537

A B S T R A C T

Purpose
The aim of International Myeloma Working Group was to develop practical recommendations for the use of magnetic resonance imaging (MRI) in multiple myeloma (MM).

Methods
An interdisciplinary panel of clinical experts on MM and myeloma bone disease developed recommendations for the value of MRI based on data published through March 2014.

Recommendations
MRI has high sensitivity for the early detection of marrow infiltration by myeloma cells compared with other radiographic methods. Thus, MRI detects bone involvement in patients with myeloma much earlier than the myeloma-related bone destruction, with no radiation exposure. It is the gold standard for the imaging of axial skeleton, for the evaluation of painful lesions, and for distinguishing benign versus malignant osteoporotic vertebral fractures. MRI has the ability to detect spinal cord or nerve compression and presence of soft tissue masses, and it is recommended for the workup of solitary bone plasmacytoma. Regarding smoldering or asymptomatic myeloma, all patients should undergo whole-body MRI (WB-MRI; or spine and pelvic MRI if WB-MRI is not available), and if they have > one focal lesion of a diameter > 5 mm, they should be considered to have symptomatic disease that requires therapy. In cases of equivocal small lesions, a second MRI should be performed after 3 to 6 months, and if there is progression on MRI, the patient should be treated as having symptomatic myeloma. MRI at diagnosis of symptomatic patients and after treatment (mainly after autologous stem-cell transplantation) provides prognostic information; however, to date, this does not change treatment selection.

J Clin Oncol 33:657-664. © 2015 by American Society of Clinical Oncology

INTRODUCTION

Bone disease, characterized by the presence of osteolytic lesions, bone fractures, or osteoporosis, is a significant cause of morbidity and mortality in multiple myeloma (MM). Therefore, the guidelines of the International Myeloma Working Group (IMWG) suggest that the presence of even asymptomatic bone disease on conventional radiography is a criterion of symptomatic MM that requires treatment.[1]

In 2009, the IMWG indicated that whole-body (WB) x-ray (WBXR) remains the gold standard for the evaluation of MM-related bone disease.[2] However, the detection limit of WBXR is low; to detect an osteolytic lesion by WBXR, a proportion of at least 30% to 50% of the trabecular bone has to be resorbed.[3] Moreover, WBXR is not a suitable technique for the diagnosis of myeloma-related osteoporosis, has low visualization of the spine and pelvis, and cannot accurately depict the cause of painful lesions in patients with MM. In previous recommendations, the IMWG supported the implementation of magnetic resonance imaging (MRI) in the absence of osteolytic lesions on WBXR.[2] However, the IMWG did not suggest the use of MRI for the definition of symptomatic myeloma. Thus, to date, a patient with focal lesions on MRI but with no lytic lesions on WBXR and with no other CRAB (hypercalcemia, renal failure, anemia, and bone disease)

Table 1. Levels of Evidence and Grades of Recommendations

Rating	Description
Level	
I	Evidence obtained from meta-analysis of multiple well-designed, controlled studies; randomized trials with low false-positive and low false-negative errors (high power)
II	Evidence obtained from at least one well-designed experimental study; randomized trials with high false-positive and/or false-negative errors (low power)
III	Evidence obtained from well-designed, quasiexperimental studies (eg, nonrandomized, controlled single-group, pre-post, cohort, time, or matched case-control studies)
IV	Evidence from well-designed, nonexperimental studies (eg, comparative and correlational descriptive and case studies)
V	Evidence from case reports and clinical examples
Grade	
A	Evidence of type I or consistent findings from multiple studies of types II, III, or IV
B	Evidence of type II, III, or IV; findings are generally consistent
C	Evidence of type II, III, or IV; findings are inconsistent
D	Little or no systematic empiric evidence

Table 2. Minimum Technical Requirements for Use of MRI in Patients With Myeloma

Type	Requirement
Coil	Target volume adapted surface-reception coil system
Examination volume	Whole spine and pelvic MRI (if WB-MRI is not available)
Orientation	Sagittal axial for spine; axial coronal for pelvis
Parameter	
Slice thickness	4 mm (definitely not > 5 mm)
Matrix	512 pixels
Weighting	T1, T2
Sequences	Sagittal T1 TSE, sagittal or coronal TIRM (STIR), axial T1 and T2 TSE, chemical shift, and T1 post contrast

Abbreviations: MRI, magnetic resonance imaging; STIR, short time inversion recovery; TIRM, turbo inversion recovery magnitude; TSE, turbo spin echo; WB, whole body.

criteria is considered to have smoldering or asymptomatic myeloma (SMM), and follow-up with no treatment is recommended. Several novel data stress the value of MRI in this setting, and we suggest that the current treatment practice be changed for these patients. Our aim was to produce useful recommendations for the use of MRI in everyday clinical practice for the management of patients with myeloma and introduce novel MRI criteria for the definition of SMM.

METHODS

An interdisciplinary panel of experts on myeloma bone disease and MRI performance in patients with myeloma developed the recommendations based on evidence of published clinical or observational studies, meta-analyses, and systematic reviews through March 2014. Expert consensus was used to propose recommendations in the absence of sufficiently published data. Levels of evidence and grades of recommendations were used according to established criteria (Table 1). The statement was drafted and circulated among all panel members, followed by subsequent rounds of revision until consensus was achieved.

MRI TECHNIQUES FOR MYELOMA

Several MRI techniques have been developed for the assessment of bone marrow involvement in MM: T1 weighted, T2 weighted with fat suppression, short time inversion recovery, and gadolinium T1 weighted with fat suppression.[4] Myeloma lesions typically show a low signal intensity on T1-weighted images, a high signal intensity on T2-weighted and short time inversion recovery images, and often enhancement on gadolinium-enhanced images.[5,6] Table 2 summarizes the minimum technical requirements of these techniques for the management of patients with myeloma.

Limitations of MRI are the prolonged acquisition time, high cost, exclusion of patients with metal devices in their bodies, difficulties in cases of claustrophobic patients, and limited field of view. To override these restrictions, a WB-MRI methodology, which does not usually require contrast infusion, was developed. The time of WB-MRI is approximately 45 minutes. Although of interest, this newer technique is not yet widely employed.

The MRI methods mentioned use MRI exquisite contrast and spatial resolution for the depiction of WB anatomy and specific tissue composition in detail. A newer MRI sequence is diffusion-weighted imaging (DWI). This functional technique demonstrates alterations in intra- and extracellular water content from disruption of the transmembrane water flux that are visible before identified changes on the morphologic routine sequences.[7-9] One disadvantage of DWI is that the apparent diffusion coefficient (ADC) is not exclusively influenced by diffusion but also by perfusion. However, improved sequences are under development to differentiate both influences.[10] DWI can be used to detect regions with bone marrow infiltration for both diagnosis and monitoring of treatment response.[11,12] In patients with MM, the ADC was reproducible[13] and correlated with bone marrow cellularity and microvessel density (MVD).[14]

The dynamic contrast-enhanced MRI (DCE-MRI) is another MRI technique in which the distribution of a contrast agent inside and outside the blood vessels is assessed by computer-based analysis of repeated images over time. The analysis provides data for blood volume and vessel permeability for the assessment of microcirculation.[15,16] More importantly, in patients with MM, DCE-MRI measurements have been correlated with marrow angiogenesis and MVD[17] as well as with angiogenic response to therapy.[18] Regarding DCE-MRI sampling rate and model, there are two pharmacokinetic models (proposed by Brix and Tofts) that have been applied in the literature. However, a comparison of these models demonstrated that the Brix model is slightly more robust.[19] Because DCE-MRI has not been established in clinical routine, no definite sequence can be recommended.

Positron emission tomography (PET) in combination with MRI is a novel and promising new methodology in which PET detects active focal lesions, while MRI shows the location of the lesions and provides information on myeloma cell infiltration of the bone marrow. Especially in patients who reach a complete remission (CR), this technique might be able to localize residual sites of disease activity and therefore may help to guide treatment in the future.[20]

MRI PATTERNS OF MARROW INVOLVEMENT

Five MRI patterns of marrow involvement in myeloma have been recognized: normal appearance of bone marrow, focal involvement (positive focal lesion is considered lesion of diameter ≥ 5 mm), homogeneous diffuse infiltration, combined diffuse and focal infiltration, and variegated or salt-and-pepper pattern with inhomogeneous bone marrow with interposition of fat islands.[21,22] Low tumor burden is usually associated with a normal MRI pattern, but a high tumor burden is usually suspected when there is diffuse hypointense change on T1-weighted images, diffuse hyperintensity on T2-weighted images, and enhancement with gadolinium injection.[23] In several studies, the percentage of symptomatic patients with each of the abnormal MRI bone marrow patterns has ranged from 18% to 50% for focal pattern, 25% to 43% for diffuse pattern, and 1% to 5% for variegated pattern.[16] The Durie-Salmon PLUS system uses the number of focal lesions (from focal or combined focal and diffuse patterns) for the staging of a patient with myeloma rather than the diffuse or salt-and-pepper pattern.[24]

MRI IN SYMPTOMATIC MYELOMA

MRI Versus Conventional Radiography and Other Imaging Techniques for Detection of Bone Involvement

MRI is more sensitive compared with WBXR for the detection of bone involvement in MM. In the largest series of patients published to date, MRI was compared with WBXR in 611 patients who received tandem autologous stem-cell transplantation (ASCT). MRI and WBXR detected focal and osteolytic lesions in 74% and 56% of the imaged anatomic sites, respectively. Furthermore, 52% of 267 patients with normal WBXR had focal lesions on MRI. More precisely, MRI detected more focal lesions compared with lytic lesions in WBXR in the spine (78% v 16%; $P < .001$), pelvis (64% v 28%; $P < .001$), and sternum (24% v 3%; $P < .001$). WBXR had better performance than MRI in the ribs (10% v 43%; $P < .001$) and long bones (37% v 48%; $P = .006$) and equal results in the skull and shoulders.[25] Similar results had been previously reported in smaller studies, where MRI was superior to WBXR for the detection of focal versus osteolytic lesions in the pelvis (75% v 46% of patients) and spine (76% v 42%), especially in the lumbar spine.[26-30] A recent meta-analysis confirmed the superiority of MRI over WBXR regarding the detection of focal lesions and showed that MRI especially outscores WBXR in the axial skeleton but not in the ribs.[31]

Although it is clear that MRI can detect bone marrow focal lesions long before the development of osteolytic lesions on WBXR, other imaging techniques such as PET combined with computed tomography (CT), CT, or WB-CT detect more osteolytic lesions compared with WBXR.[31] Do we have any evidence that MRI is superior to the other techniques in depicting bone involvement in myeloma? In a study with 41 patients with newly diagnosed MM, WB-MRI was found superior to WB-CT in detecting lesions in the skeleton.[32] In a prospective study, Zamagni et al[33] compared MRI of the spine and pelvis with WBXR versus PET-CT in 46 patients with MM at diagnosis. Although PET-CT was superior to WBXR in detecting lytic lesions in 46% of patients (19% had negative WBXR), it failed to reveal abnormal findings in 30% of patients who had abnormal MRI in the

same areas, mainly of diffuse pattern. In that study, the combination of spine and pelvic MRI with PET-CT detected both medullary and extramedullary active myeloma sites in almost all patients (92%). Nevertheless, the Arkansas group was not able to confirm any superiority of MRI over PET-CT in the detection of more focal lesions in a large number of patients (n = 303) within the Total Therapy 3 protocols.[34] Still, in 188 patients who had ≥ one focal lesion on MRI, MRI was superior to PET-CT regarding the detection of higher number of focal lesions ($P = .032$). Furthermore, in this study, the presence of diffuse marrow pattern was not taken into consideration as an abnormal MRI finding.[34] Compared with MIBI (sestamibitechnetium-99m) scan, WB-MRI detected more lesions in the vertebrae and long bones, produced similar results in the skull, and was inferior in the ribs.[35] One important question on this point is the value of WB-MRI, which is not available everywhere, over MRI of the spine and pelvis. In 100 patients with MM or monoclonal gammopathy of undetermined significance (MGUS) who underwent WB-MRI, 10% presented with focal lesions merely in the extra-axial skeleton. These lesions would have been ignored if only MRI of the spine and pelvis had been performed.[36]

Other advantages of MRI over WBXR and CT include the discrimination of myeloma from normal marrow[4,37]; this finding can help in the differential diagnosis between myeloma and benign cause of a vertebral fracture. This is of extreme importance in cases of patients with a vertebral fracture and no other CRAB criteria or lytic lesions. MRI can also accurately illustrate the spinal cord and/or nerve root compression for surgical intervention or radiation therapy.[2,4] Furthermore, the presence of soft tissue extension of MM and presence of extramedullary plasmacytomas, which develop in approximately 10% to 20% of patients during the course of their disease, can be precisely visualized by WB-MRI.[38-40] MRI can also help in the better evaluation of avascular necrosis of the femoral head[41] and presence of soft tissue amyloid deposits.[42] Moreover, tumor load can be assessed and monitored by MRI, even in patients with nonsecretory or oligosecretory MM.[43]

Consensus Statement

MRI is the imaging gold-standard method for the detection of bone marrow involvement in MM (grade A). We stress that MRI detects bone marrow involvement and not bone destruction. MRI of the spine and pelvis can detect approximately 90% of focal lesions in MM, and thus, it can be used in cases where WB-MRI is not available (grade B). MRI is the procedure of choice to evaluate a painful lesion in patients with myeloma, mainly in the axial skeleton, and detect spinal cord compression (grade A). MRI is particularly useful in the evaluation of collapsed vertebrae, especially when myeloma is not active, where the possibility of osteoporotic fracture is high (grade B).

Prognostic Value of MRI

The prognostic significance of MRI findings in symptomatic myeloma has been evaluated. The largest study in the literature included 611 patients who received tandem ASCT-based protocols. Focal lesions detected by spinal MRI and not seen on WBXR independently correlated with overall survival (OS). Resolution of the focal lesions on MRI after treatment occurred in 60% of the patients who had superior survival. At disease progression after CR, MRI revealed new focal lesions in 26% of patients, enlargement of previous focal lesions in 28%, and both features in 15%.[25] In a more recent analysis

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by the same group involving 429 patients, patients who had > seven focal lesions on MRI (n = 147) had a 73% probability of 3-year OS versus 86% for those who had zero to seven focal lesions (n = 235) and 81% for those who had diffuse pattern of marrow infiltration (n = 47; $P = .04$). PET-CT and WBXR also produced similar results in the univariable analysis. In the multivariable analysis, from the imaging variables, only the presence of > two osteolytic lesions on WBXR at diagnosis and presence of > three focal lesions on PET-CT 7 days after ASCT had independent prognostic value for inferior OS ($P = .01$ and .03, respectively). However, we have to mention the high percentage of patients (232 [54%] of 429) who had no detectable osteolytic lesions by WBXR and the absence of evaluation of diffuse MRI pattern in this study.[44]

The MRI pattern of marrow infiltration has also been reported to have prognostic significance in newly diagnosed patients with symptomatic disease.[23,45,46] In the conventional chemotherapy era, Moulopoulos et al[23] reported that the median OS of patients with newly diagnosed MM was 24 months if they had diffuse MRI pattern versus 51, 52, and 56 months for those with focal, variegated, and normal patterns, respectively ($P = .001$). This is possibly because diffuse MRI marrow pattern correlates with increased angiogenesis and advanced disease features.[47,48] The same group also reported the prognostic value of MRI patterns in 228 patients with symptomatic MM who received first-line regimens based on novel agents. Patients with diffuse pattern had inferior survival compared with patients with other MRI patterns; moreover, the combination of diffuse MRI pattern, International Staging System stage III, and high-risk cytogenetics could identify a group of patients with poor survival (ie, median, 21 months; probability of 3-year OS, 35%).[46] Another study in 126 patients with newly diagnosed symptomatic myeloma who underwent ASCT showed that the diffuse and variegated MRI patterns had an independent predictive value for disease progression (hazard ratio [HR], 1.922; $P = .008$).[48] Finally, in patients with progressive or relapsed MM, an increased DCE-MRI signal indicated shorter progression-free survival, possibly because of its association with higher MVD.[15]

Consensus Statement

The number of MRI focal lesions (> seven; grade A) and presence of diffuse pattern (grade B) correlate with inferior survival. Prospective clinical studies are needed to define if these patients have to be treated in a different or more aggressive way.

MRI and Response to Antimyeloma Therapy

An interesting finding is that a change in MRI pattern correlates with response to therapy. Moulopoulos et al[49] first reported in the era of conventional chemotherapy that CR is characterized by complete resolution of the preceding marrow abnormality, whereas partial response is characterized by changeover of diffuse pattern to variegated or focal pattern. In a retrospective study that was conducted in the era of novel agents, response to treatment was compared with changes in infiltration pattern on WB-MRI before and after ASCT (n = 100). There was a strong correlation between response to antimyeloma therapies and changes in both diffuse ($P = .004$) and focal ($P = .01$) MRI patterns. Furthermore, the number of focal lesions on second MRI was of prognostic significance for OS ($P = .001$).[50] Another study in 33 patients who underwent ASCT showed that WB-MRI data demonstrated progressive disease in 10 patients (30%) and response to high-dose therapy in 23 (70%). Eight (80%) of the 10 patients with progressive disease revealed intramedullary lesions, and two patients

(20%) had intra- and extramedullary lesions. WB-MRI had a sensitivity of 64%, specificity of 86%, positive predictive value of 70%, negative predictive value of 83%, and accuracy of 79% for detection of remission.[51] This study supports that one of the disadvantages of MRI is that it often provides false-positive results because of persistent nonviable lesions. Thus, PET-CT might be more suitable than MRI for determination of remission status.[52] Indeed, in a large study of 191 patients, PET-CT revealed faster change of imaging findings than MRI in patients who responded to therapy.[53] It seems that PET-CT normalization after treatment can offer more information compared with MRI for the better definition of CR.[54]

To improve the results of MRI for the most accurate detection of remission, DW-MRI has been recently used. In a first preliminary report, ADC values in active myeloma were significantly higher than marrow in remission.[55] Furthermore, the mean ADC increased in 95% of responding patients and decreased in all nonresponders (n = 5; $P = .002$). An increase of ADC by 3.3% was associated with response, having a sensitivity of 90% and specificity of 100%. Furthermore, there was a negative correlation between changes of ADC and changes of biochemical markers of response ($r = -0.614$; $P = .001$).[56] Large prospective clinical studies are definitely justified by these results.

Consensus Statement

MRI might help in the better definition of CR (grade D; panel consensus). Nevertheless, the high number of false-positive results suggests that its combination with methods that reveal active lesions (ie, PET-MRI) or another imaging method, such as PET-CT, might be of more value in this setting. Thus, the systematic performance of MRI for the follow-up of patients, before or after different therapies, in the absence of clinical indications is not recommended. Novel clinical studies have to include MRI for the response evaluation in an effort to clarify the role of MRI in this important field of myeloma therapy.

VALUE OF MRI IN DEFINITION OF SMM

The presence of lytic lesions by WBXR is included in the definition of symptomatic myeloma, based on studies showing that patients with ≥ one lytic lesion on WBXR have a median time to progression (TTP) of 10 months.[57] However, in patients with no osteolytic lesions on WBXR, MRI reveals abnormal marrow appearance in 20% to 50%[22,23,58-60]; these patients are at higher risk for progression. Moulopoulos et al[58] reported that patients with SMM and abnormal MRI studies required therapy after a median of 16 months versus 43 months for those with normal MRI ($P < .01$). Hillengass et al[59] evaluated WB-MRI in 149 patients with SMM. Focal lesions were detected in 42 patients (28%), while > one focal lesion was present in 23 patients (15%) who had high risk of progression (HR, 4.05; $P < .001$). The median TTP was 13 months, and the progression rate at 2 years was 70%. On multivariable analysis, presence of > one focal lesion remained a significant predictor of progression after adjusting for other risk factors, including bone marrow plasmacytosis, serum and urine M protein levels, and suppression of uninvolved immunoglobulins. In the same study, diffuse marrow infiltration on MRI was also associated with increased risk for progression (HR, 3.5; $P < .001$). Kastritis et al[60] also showed in a study of 98 patients with SMM that abnormal marrow pattern on MRI of the spine, which was present in

21% of patients, was associated with high risk of progression, with a median TTP to symptomatic myeloma of 15 months ($P = .001$).

The identification of patients with SMM who are at high risk for progression is of great importance, because these patients may benefit from immediate therapy. A recent randomized study from the Spanish Myeloma Study Group compared the combination of lenalidomide plus low-dose dexamethasone (Rd) versus observation in patients with high-risk SMM (MRI was not used for defining high-risk SMM). TTP was significantly longer with Rd compared with observation (median, not reached v 21 months, respectively; $P < .001$). More importantly, Rd offered OS advantage (probability of 3-year survival, 94% v 80%, respectively; $P = .03$).[61]

An important issue is whether patients who have ≥ two small focal lesions (< 5 mm) should be considered as having symptomatic myeloma and how to manage them. Recently, the Heidelberg group analyzed data of 63 patients with SMM who had ≥ two WB-MRIs performed for follow-up before progression to symptomatic disease. The definition of radiologic progression according to MRI findings included one of the following: development of a new focal lesion, increase of the diameter of an existing focal lesion, or detection of novel or progressive diffuse MRI pattern. The second MRI was performed 3 to 6 months after the performance of the first MRI. Evaluation of response according to IMWG criteria was also performed. Progressive disease according to MRI was observed in approximately 50% of patients, whereas 40% of patients developed symptomatic MM based on the CRAB criteria. In the multivariable analysis, progressive disease according to MRI was an independent prognostic factor for progression. Patients with stable MRI findings had no higher risk of progression, even when focal lesions were present on the initial MRI.[62] Prospective clinical trials should be conducted to confirm these findings.

Consensus Statement

We recommend that patients with > one unequivocal focal lesion (diameter of > 5 mm) should be considered to have symptomatic myeloma that requires therapy (grade B). Patients with equivocal focal lesions should repeat the MRI after 3 to 6 months, and in cases of MRI progression, patients should be considered as symptomatic patients who need therapy (grade C; panel consensus). The biopsy of such lesions should be encouraged. Regarding diffuse MRI marrow pattern, we need additional studies before its incorporation into the definition of symptomatic myeloma.

MRI FINDINGS IN MGUS

MGUS by definition is characterized by the absence of osteolytic lesions. However, patients with MGUS have higher incidences of osteoporosis and vertebral fractures compared with the normal population.[63,64] In a small study that included 37 patients with MGUS or SMM, MRI abnormalities were detected in 20%. These patients had a higher TTP to symptomatic myeloma compared with patients with a normal MRI who did not experience progression after a median follow-up of 30 months.[65] A prospective study involving 331 patients with MGUS or SMM revealed that the detection of multiple (> one) focal lesions by MRI conferred an increased risk of progression.[66] In another large study, which included only patients with MGUS (n = 137) who underwent WB-MRI at diagnosis, a focal infiltration pattern was detected in 23%. Independent prognostic factors for progression to symptomatic myeloma included the presence and number of focal lesions and value of M-protein.[67]

Consensus Statement

WB-MRI identifies patients with MGUS with focal lesions that possibly reflect infiltration by monoclonal plasma cells in the bone marrow. These patients seem to have increased risk of progression to myeloma. To date, MRI is not recommended as part of the routine workup for patients with MGUS unless there are clinical features that increase suspicion.

MRI AND SOLITARY BONE PLASMACYTOMA

The diagnosis of solitary plasmacytoma of the bone (SBP) includes the presence of a solitary bone lesion, with a confirmed infiltration by plasma cells on biopsy of the lesion, absence of clonal plasma cells on the trephine bone marrow biopsy, and no CRAB criteria met. Although definitive radiotherapy usually eradicates the local disease, a majority of patients will develop MM because of the growth of previously occult lesions not detected by WBXR.[39] Moulopoulos et al[38] reported that spinal MRI revealed additional focal lesions in four of 12 patients with SBP. After treatment with radiotherapy to the painful lesion, three patients developed systemic disease within 18 months from diagnosis. Furthermore, Liebross et al[68] observed that among patients with SBP with spinal disease, seven of eight staged by WBXR

Table 3. Recommendations for Use of MRI in Myeloma, MGUS, and SBP

Recommendation	Grade
Symptomatic myeloma	
MRI is imaging gold-standard method for detection of bone marrow involvement in MM	A
MRI of spine and pelvis can be used in cases where WB-MRI is not available	B
MRI is procedure of choice to evaluate painful lesion and spinal cord compression	A
MRI can differentiate malignant from nonmalignant vertebral fractures	B
MRI provides accurate visualization of soft tissue extension and extramedullary plasmacytoma	A
Focal pattern provides prognostic information	A
Diffuse pattern also correlates with inferior prognosis	B
MRI might help in better definition of CR	D
MRI is not recommended for treatment follow-up	
Asymptomatic myeloma	
Patients with > one unequivocal focal lesion (diameter > 5 mm) should be considered to have symptomatic myeloma that requires therapy	B
Patients with equivocal focal lesions should repeat MRI after 3 to 6 months; in cases of MRI progression, patients should be considered to be symptomatic and to require therapy	C
MGUS and SBP	
MRI is not recommended as part of routine workup of patients with MGUS unless there are clinical features that increase suspicion	
MRI should be part of staging procedures in patients with SBP	A

Abbreviations: CR, complete response; MGUS, monoclonal gammopathy of undetermined significance; MM, multiple myeloma; MRI, magnetic resonance imaging; SBP, solitary bone plasmacytoma; WB, whole body.

alone developed MM, compared with only one of seven patients who also underwent spinal MRI.

Consensus Statement

MRI should be part of the staging procedures in patients with SBP to better assess the extent of the local tumor and reveal occult lesions elsewhere (grade A).

DISCUSSION

In summary, MRI describes the pattern of myelomatous infiltration of the bone marrow and is the procedure of choice for the evaluation of painful lesions in patients with myeloma for the detection of spinal cord compression and differentiation of malignant from nonmalignant vertebral fractures. MRI provides significant prognostic information in patients with symptomatic disease and may be found useful in the better definition of CR. More importantly, MRI can reclassify patients with SMM to symptomatic MM, and patients with > one unequivocal focal lesion (diameter of > 5 mm) should be considered as having symptomatic myeloma that requires therapy. Finally, MRI is part of the staging workup of SBP. A summary of the recommendations is listed in Table 3.

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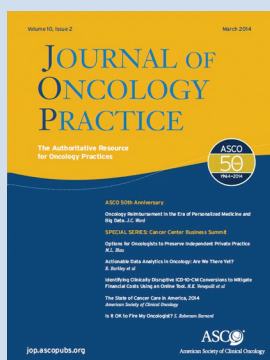
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GLOSSARY TERMS

dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI): a magnetic resonance imaging acquisition strategy involving multiple scans over a set volume during injection of a magnetic resonance contrast agent.

microvessel density (MVD): a quantification technique used to assess the number of vessels in a particular tumor specimen using immunohistochemical stains for endothelial markers. High MVD has been found to be associated with poor prognosis in patients with solid tumors.

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

Role of Magnetic Resonance Imaging in the Management of Patients With Multiple Myeloma: A Consensus Statement

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