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Added Value of Contrast-Enhanced T1-Weighted and Diffusion-Weighted Sequences for Characterization of Incidental Findings on Whole Body Magnetic Resonance Imaging in Plasma-Cell Disorders

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Abstract

Incidental findings on whole body magnetic resonance imaging (WBMRI) in myeloma may necessitate additional investigations. Incidence, characterization, and significance of incidental findings at WBMRI in 100 patients with plasma-cell disorders were calculated. A total of 348 findings were detected in 97 of 100 patients; 38 of 348 findings were indeterminate, and no additional cancers were detected. Incidental findings are common, but the majority can be characterized at WBMRI and are not significant.

Background: Whole body magnetic resonance imaging (WBMRI) is currently recommended by guidelines for the assessment of myeloma. This will inevitably result in incidental findings. We aimed to assess the frequency of extraskeletal incidental findings and the added value of contrast-enhanced (CE) T1-weighted (T1-W) and diffusion-weighted (DWI) sequences for their characterization in a single WBMRI examination. **Patients and Methods:** We performed 1.5 T WBMRI in 100 patients (53 female; median age, 65 years) with plasma-cell disorders from January 2014 to July 2017. T2-weighted sequences were reviewed initially for incidental findings, followed by sequential review of T1-W, CE T1-W, and DWI sequences for lesion characterization. Descriptive statistics were undertaken. **Results:** A total of 348 incidental findings were detected in 97 (97%) of 100 patients; only 38 (10.9%) of 348 findings were indeterminate. T1-W sequences increased diagnostic confidence in the characterization of 12 (31.6%) of 38; CE T1-W sequences in the characterization of 16 (50%) of 32; and DWI increased diagnostic confidence in 21 (55.3%) of 38 compared to the T2-weighted sequence alone. **Conclusion:** Incidental findings are common, but the majority are of no clinical consequence. No additional cancers were noted in our series. DWI and CE T1-W sequences increased diagnostic confidence in 50% of indeterminate findings and may reduce the need for further investigation.

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Introduction

The revised International Myeloma Working Group guidelines now state that the presence of more than one focal magnetic resonance imaging (MRI) bone lesion > 5 mm is diagnostic of myeloma.[1] The International Myeloma Working Group guidelines also specifically advocate whole body magnetic resonance imaging (WBMRI) in the initial assessment of smoldering myeloma because patients are at increased risk of progression to myeloma. With its

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excellent tissue contrast and high spatial resolution, WBMRI provides a comprehensive approach to skeletal and extraskeletal assessment. WBMRI will define disease burden through the number and location of skeletal lesions, the pattern of disease, and the presence of extraosseous sites, as well as clinically significant complications such as fractures and cord/cauda equina compression.

Thus clinical practice guidelines are changing. Whole body MRI (WBMRI) is now recommended in the United Kingdom by the National Institute for Health and Care Excellence as the first-line imaging test for suspected and newly diagnosed myeloma.[2] The 2017 British Society of Haematology guidelines also recommend WBMRI as the first-line imaging test in asymptomatic patients with 10% to 60% plasma cells on trephine biopsy or bone marrow aspirate, or an M protein > 30 g/L.[3]

Incidental findings are inevitable with whole body studies and may require further investigations, adding to patient anxiety. Up to 58% of incidental findings may be indeterminate in nature.[4] We hypothesized that a comprehensive WBMRI protocol including T2-weighted (T2-W), T1-weighted (T1-W), contrast-enhanced (CE) T1-W, and diffusion-weighted (DWI) sequences will improve the characterization of incidental findings and potentially reduce the need for further investigations. We thus aimed to determine (1) the frequency of incidental findings in patients undergoing WBMRI for plasma-cell disorders in our institution, (2) their clinical significance, and (3) the added value of T1-W, CE T1-W, and DWI sequences in the characterization of indeterminate findings.

Patients and Methods

Patients

Institutional review board approval was obtained; the need for informed consent was waived for this retrospective audit of practice. One hundred patients with suspected or proven plasma-cell disorders underwent WBMRI between January 2014 and July 2017. There were 53 female and 47 male patients with a median age of 65 years (range, 38-90 years) who had the following confirmed diagnoses: myeloma = 63, smoldering myeloma = 11, monoclonal gammopathy of unknown significance = 12, plasmacytoma = 6, and other diagnoses = 8 (suspected myeloma = 3, amyloidosis = 3, lymphoma = 1, demyelinating neuropathy = 1).

Imaging and Image Analysis

WBMRI consisting of T2-W, T1-W, DWI (b-value = 50 and 900 s/mm^2), and CE T1-W sequences from the skull vertex to knees was performed at 1.5 T (Magnetom Aera; Siemens Healthcare, Erlangen, Germany) (Table 1). WBMRI study duration was approximately 45 minutes. Intravenous contrast administration (20 mL gadoterate meglumine) was only possible in 82 (82%) of 100 patients because of renal impairment.

T2-W sequences were reviewed initially for incidental findings, followed by a dedicated review of T1-W, CE T1-W, and DWI sequences including apparent diffusion coefficient maps by a staff radiologist with 7 years of MRI experience. Findings, their site, and likely diagnoses were noted. On the basis of review of T2-W sequences, these findings were also categorized as follows: I, common in asymptomatic subjects/not clinically significant; IIA, benign and potentially clinically significant; IIB, indeterminate and potentially malignant; or III, requiring urgent clinical input.

For indeterminate findings that could not be characterized initially on the T2-W sequence, the likelihood of malignancy was recorded for each additional sequence (T1-W, CE T1-W, and DWI) as follows: I, benign, II, probably benign, III, indeterminate, IV, probably malignant, or V, malignant.

The diagnostic confidence for likely diagnosis was also scored for T1-W, CE T1-W, and DWI sequences independent of each other

Table 1 Whole Body Magnetic Resonance Imaging Protocol

Image Contrast	T1-W	DWI (b-Values 50 and 900 s/mm^2)	T2-W	T1-W (Pre- and Postcontrast)
Sequence	Dixon 3-D FLASH	DW-EPI	HASTE	Dixon 3-D FLASH
Imaging plane	Axial	Axial	Axial	Coronal
No. of slices per imaging station	40	40	40	128
Acquired slice thickness (mm)	10	5	5	10
Reconstructed slice thickness (mm)	5	5	5	2.0
Slice gap (mm)	0	0	0	0
FOV (mm)	500	500	500	500
Acquired voxels (mm × mm)	2 × 1.6	3.9 × 3.9	2.0 × 2.0	1.9 × 0.17
Reconstructed matrix	640	256	512	288
Reconstructed voxels (mm × mm)	0.8 × 0.8	2.0 × 2.0	1.0 × 1.0	1.7 × 1.7
Phase-encoding direction	AP	AP	AP	FH
TR (ms)	6.62	6270	400	6.76
TE (ms)	TE1 = 2.39, TE 2 = 4.77	67	92	TE1 = 2.39, TE2 = 4.77
Flip angle (degrees)	10	90	90; refocusing angle 180	10
No. of signal averages	1	2 (b50), 5 (b900)	1	1
Fat suppression	NA	STIR	None	NA
Acquisition time (per station)	10 sec	3 min 22 sec	16 sec	20 sec

Abbreviations: AP = anterior to posterior; DW-EPI = diffusion-weighted echo planar imaging; FH = foot to head; FLASH = fast low-angle shot; FOV = field of view; STIR = short TI inversion recovery; TE = echo time; TR = repetition time; W = weighted.

in order to ascertain the added value of each additional sequence for lesion characterization compared to the initial T2-W sequence.

Reference Standard

Electronic patient records were reviewed in order to confirm whether the incidental findings detected at WBMRI resulted in further investigations, including further imaging tests and biopsy, and the final diagnosis. Where no further information was available, clinical consensus regarding the clinical significance and whether further management would have been undertaken was agreed by 2 hematologists. Clinical significance was graded as follows: unknown, low significance, moderate significance (meriting further routine investigation), and high significance (meriting urgent investigation).

Statistical Analysis

Descriptive statistics were undertaken by SPSS 24 software (IBM, Armonk, NY).

Results

A total of 348 incidental findings were detected on the T2-W sequences in 97 (97%) of 100 patients (median, 3 findings per patient; range, 1-9 findings). The most common findings are summarized in Table 2.

A total of 197 (56.6%) of 348 findings were classified as category I (benign/not clinically significant), 113 (32.5%) of 348 findings were classified as category IIA (benign and potentially clinically significant), and 38 (10.9%) of 348 findings were classified as category IIB (indeterminate and potentially malignant). There were no category III (clinically urgent) findings.

The category IIB (indeterminate) findings are summarized in Table 3 and were located at the following sites: liver (n = 7), spleen (n = 2), adrenal (n = 5), prostate (n = 5), lymph nodes (n = 5), and others (n = 14). Thirty-four patients had one indeterminate finding; 2 patients had 2 indeterminate findings; 2 patients had 3 and 4 indeterminate findings respectively.

Each additional sequence (T1-W, CE T1-W, or DWI) resulted in increased diagnostic confidence for lesion characterization compared to the initial T2-weighted imaging (Figure 1). T1-weighted Dixon sequences increased diagnostic confidence in the characterization of 12 (31.6%) of 38 findings because of its ability to demonstrate microscopic fat and hemorrhage; 5 indeterminate adrenal lesions were confirmed as adrenal adenomas with the T1-W Dixon sequences. CE T1-W sequences, only possible in 82 (82%) of 100 patients because of renal impairment in the remaining patients, increased diagnostic confidence in characterization of 16 (50%) of 32 findings compared to T2-W imaging alone and was particularly helpful for hepatic and renal lesions. DWI sequences increased diagnostic confidence in characterization of 21 (55.3%) of 38 findings compared to T2-W imaging alone. T1-weighted Dixon, DWI, and CE T1-W sequences did not improve characterization of 2 subcentimeter pulmonary nodules.

In 16 (42.1%) of 38 patients, further investigation of indeterminate findings was recommended (further imaging = 5, histology = 11). Eight (50%) of 16 patients were investigated further. For the remaining 8 findings, one patient died before further investigation could be undertaken. The cause of death was progressive myeloma, and the hepatosplenic lesions likely represented extramedullary disease sites. Of the 7 findings not investigated initially, 5 of 7 findings scored as low clinical significance. Two of 7 findings were scored as moderate by clinical consensus, for whom further investigations were recommended; transvaginal ultrasound in patient 5, found to have incidental endometrial thickening, and serum prostate-specific antigen with or without histology in patient 7 with possible incidental prostatic lesion (Table 4).

Table 2 Summary of Incidental Findings by Body Region

Incidental Finding	N	%	Category
Intracranial			
Sinusitis	34	9.8	I
Small vessel disease	16	4.6	IIA
Infarct	3	0.9	IIA
Vestibular schwannoma	1	0.3	IIB
Neck			
Thyroid lesion/cyst	6	1.7	I
Cervical/supraclavicular fossa lymph node	2	0.6	IIB
Parotid Warthin tumor	1	0.3	IIB
Chest			
Pleural effusion	7	2.0	IIA
Pulmonary lesion	3	0.9	IIB
Cardiomegaly	2	0.6	IIA
Chest wall lipoma	2	0.6	I
Abdomen			
Hepatic/renal/splenic cysts	80	23.0	I
Colonic diverticulosis	18	5.2	IIA
Cholelithiasis	9	2.6	IIA
Indeterminate liver/splenic lesion	7	2.0	IIB
Adrenal lesion/thickening	5	1.4	IIB
Pancreatic cystic lesion	5	1.4	IIB
Pelvis			
Uterine fibroid	18	5.2	IIA
Prostate lesion	5	1.4	IIB
Adnexal lesion	5	1.4	IIB
Adenomyosis	2	0.6	IIA
Inguinal hernia	2	0.6	IIA
Proximal Lower Limb			
Baker cyst	2	0.6	IIA
Knee effusion	1	0.3	IIA

No additional new malignancies were detected in this cohort. There were 3 cases of known concurrent malignancy (2 prostate cancer and 1 parotid Warthin tumor). There were also 2 cases of extramedullary plasmacytoma within lymph nodes. After exclusion of the 3 cases of known malignancy, 19 (54.3%) of 35 indeterminate findings could be fully characterized via T1-Dixon, DWI, and/or CE T1-W sequences such that no further investigations were required.

Discussion

Incidental findings are relatively common in patients with plasma-cell disorders undergoing WBMRI and were present in 97% of patients in our cohort. The majority could be characterized fully

Table 3 Indeterminate Findings by Various Imaging Modalities, Risk of Malignancy Scores, and Final Diagnoses

Indeterminate Finding (Malignancy Likelihood on T2-W Images)	T1-W	CE T1-W	DWI	Further Management Advised	Further Management Performed	Final Diagnosis or Management Recommended
Adrenal lesion (3)	II (1)	I (3)	I (3)	N	NA	Adrenal adenoma
Adrenal lesion (3)	II (1)	I (3)	I (3)	N	NA	Adrenal adenoma
Adrenal lesion (3)	II (1)	I (3)	I (3)	N	NA	Adrenal adenoma
Adrenal lesion (3)	II (1)	I (3)	I (3)	N	NA	Adrenal adenoma
Adrenal enlargement (3)	II (1)	I (3)	I (3)	N	NA	Adenomatous hyperplasia
Adnexal lesion (2)	I (2)	II (3)	II (3)	Y	N	Dedicated pelvic imaging recommended; interval WBMRI demonstrated reduction in size
Endometrial thickening (3)	II (1)	I (3)	II (1)	N	NA	Intracavitary hemorrhage
Endometrial thickening (3)	I (3)	II (3)	II (3)	Y	N	No further investigation performed
Liver lesion (2)	I (2)	I (2)	II (1)	N	NA	Benign cyst
Liver lesion (3)	I (3)	—	II (2)	Y	Y	Hemangioma (dedicated hepatic MRI)
Liver lesion (3)	I (3)	II (1)	I (3)	N	NA	Hemangioma
Liver lesion (4)	I (4)	II (5)	II (5)	Y	Y	Hemangioma (liver biopsy)
Liver lesion (4)	I (4)	II (4)	II (4)	Y	N	Patient died before further investigation could be performed
Subcentimeter liver lesion (3)	I (3)	I (3)	I (3)	Y	N	Dedicated hepatic MRI suggested; no further imaging performed
Right upper lobe lung lesion, ipsilateral, mediastinal, and hilar node (3)	I (3)	—	II (4)	Y	Y	Tuberculosis with resolution of imaging findings after treatment
Subcentimeter lung lesion (2)	I (2)	I (2)	I (2)	Y	N	Stable on follow-up imaging
Subcentimeter lung lesion (3)	I (3)	—	I (3)	Y	N	Follow-up CT chest recommended as per British Thoracic Society guidelines; no further imaging performed
Parotid lesion (3)	II (3)	II (4)	I (3)	N	NA	Warthin tumor
Pancreatic lesion (2)	I (2)	II (1)	II (1)	N	NA	Benign pancreatic cyst
Pancreatic lesion (2)	I (2)	II (1)	II (1)	N	NA	Benign pancreatic cyst
Prostate lesion (3)	I (3)	I (3)	II (4)	N	NA	Prostate cancer (previously diagnosed)
Prostate lesion (3)	I (3)	—	II (4)	N	NA	Prostate cancer (previously diagnosed)
Prostate lesions (3)	I (3)	I (3)	II (4)	Y	Y	Normal serum PSA; no further investigation
Prostate lesion (2)	I (2)	I (2)	II (3)	Y	N	Correlation with serum PSA level with or without histology recommended; no further investigation
Prostate lesion (3)	I (3)	I (3)	I (3)	Y	Y	Reviewed by urology
Renal lesion (4)	I (4)	II (5)	I (4)	Y	Y	Oncocytoma (surgery)
Renal lesion (3)	II (1)	II (1)	I (3)	N	NA	Hemorrhagic renal cyst
Renal lesion (2)	II (1)	—	I (2)	N	NA	Hemorrhagic renal cyst
Splenic lesion (4)	I (4)	II (4)	II (4)	N	NA	Patient died before further investigation could be performed
Perinephric thickening (2)	II (1)	—	I (2)	N	NA	Perinephric hematoma
Retroperitoneal cystic lesion (3)	I (3)	II (2)	II (2)	N	NA	Benign nerve sheath tumor
Supraclavicular nodes (3)	I (3)	II (4)	II (4)	Y	Y	Plasmacytoma

Table 3 Continued

Indeterminate Finding (Malignancy Likelihood on T2-W Images)	T1-W	CE T1-W	DWI	Further Management Advised	Further Management Performed	Final Diagnosis or Management Recommended
Supraclavicular and cervical nodes (3)	I (3)	I (3)	I (3)	Y	N	Clinical correlation with or without cytology recommended; no further investigation
Supraclavicular nodes (4)	I (4)	II (4)	II (4)	Y	Y	Plasmacytoma
Abdominopelvic nodes (4)	I (4)	II (4)	II (4)	N	NA	(Same patient as above)
Paravertebral soft tissue (4)	I (4)	II (4)	II (4)	N	NA	(Same patient as above)
Gluteus muscle lesion (2)	II (1)	—	I (2)	N	NA	Lipoma
Seminal vesicle lesion (3)	II (1)	I (3)	II (2)	N	NA	Seminal vesicle hemorrhage

Numbers in parentheses indicate new malignancy likelihood based on that sequence.
Abbreviations: CE = contrast enhanced; CT = computed tomography; DWI = diffusion weighted; I = no improvement in diagnostic confidence; II = improved diagnostic confidence in lesion characterization; MRI = magnetic resonance imaging; NA = not applicable; PSA = prostate-specific antigen; W = weighted; WBMRI = whole body magnetic resonance imaging.

with a comprehensive protocol such that no further investigations were required. Over half of the detected incidental findings were classified as not clinically significant or common in asymptomatic subjects. No new malignancies were detected in our cohort, although there were preexisting malignancies and extraosseous sites of disease.

T1-W Dixon sequences were helpful in the characterization of lesions containing microscopic fat (eg, adrenal adenoma) and macroscopic fat (eg, lipoma), as well as in the detection of hemorrhage (eg, hemorrhagic material within the uterine cavity and hemorrhagic renal cysts). CE T1-W sequences were particularly helpful in the characterization of hepatic and renal lesions. DWI sequences assisted in the characterization of prostatic lesions, hepatic lesions, and lymph nodes.

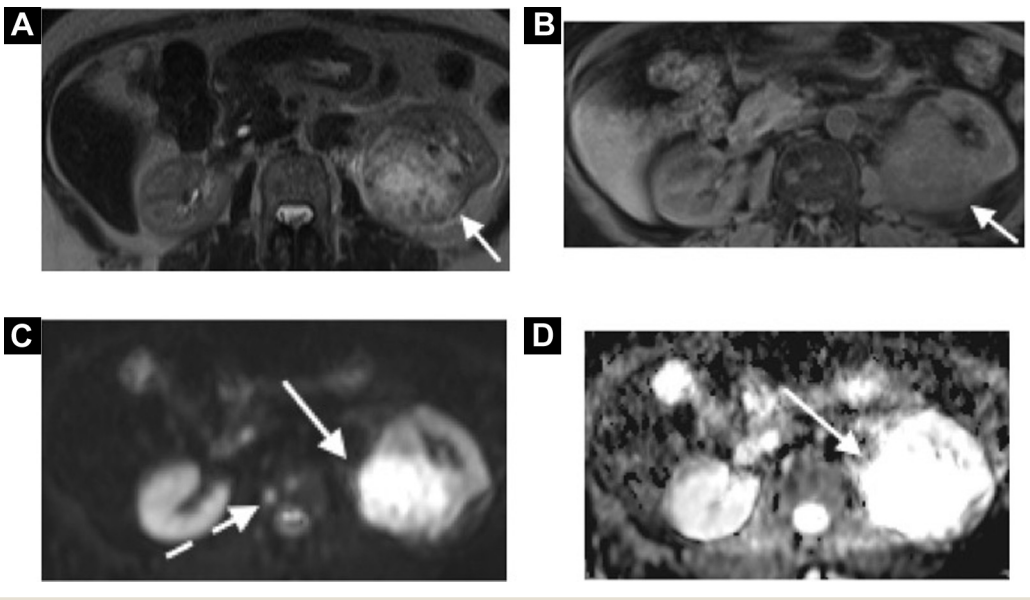
Our study reports a higher percentage of incidental findings than previously published WBMRI studies of various populations, where incidental findings have been found in up to 80% of patients.[5] In the general population-based Study of Health in Pomerania (SHIP), incidental findings were detected in 36.2% of participants (n = 2500), 5.9% of which were malignant.[4] In the SHIP study, incidental findings were categorized as I (normal/common in asymptomatic subjects), II (requiring further medical evaluation), or III (requiring immediate referral). In another study, incidental findings were detected in 42% of neurofibromatosis patients (n = 247),[6] whereas among a cohort of lymphoma patients (n = 119), 79.8% had one or more incidental finding, although only 6% were classified as clinically significant.[5]

There is only one other study to date evaluating incidental findings in WBMRI in myeloma, in which incidental findings were detected in 38% of patients.[7] In this retrospective study, the authors reviewed WBMRI (comprising axial DWI sequences with corresponding apparent diffusion coefficient maps and T1-W and T2-W sagittal whole spine sequences) in 110 patients. Seventy incidental findings were documented, of which 14 (20%) were equivocal or indeterminate. Clinical correlation and review of previous imaging was recommended as the initial action in 57% (8/14 patients) with indeterminate incidental findings, and only 3% required further characterization as the initial action.

The comparatively higher incidental finding detection rate in our cohort compared to this study partly reflects the differences in imaging protocol. The WBMRI protocol used in the study by Wale et al[7] only included axial DWI sequences, whereas we used a more comprehensive protocol of T2-W, T1-W, CE T1-W, and DWI sequences. Greater standardization of WBMRI protocols could reduce such variances. The greater proportion of incidental findings requiring further investigation in our cohort may also be partially attributed to variations in individual radiologist threshold for reporting some incidental findings and also intrinsic differences in the incidental findings encountered. For example, no prostatic lesions were reported in the study by Wale et al.

There are no studies to date that have specifically addressed the value of individual sequences in characterizing incidental findings. The value of DWI sequences in the baseline assessment of focal and diffuse marrow infiltration is clear,[8] and there is growing evidence for its use in myeloma response assessment.[9] Contrast-enhanced sequences are not used in all WBMRI protocols, particularly given the prevalence of renal impairment in this population;

Figure 1 Various Imaging Results of Patient With Myeloma. (A) Whole Body MRI 1.5 T Selected Axial T2 HASTE. (B) T1-Dixon Water Only. (C) DWI (B900). (D) ADC. Imaging Revealed Incidental Complex, Cystic Left Renal Mass (Solid White Arrow). Patient Underwent Nephrectomy With Histologic Diagnosis of Oncocytoma. Also Evident Is Focal Vertebral Body Myeloma Lessons (C, Broken Arrow)



Abbreviations: ADC = apparent diffusion coefficient; DWI = diffusion weighted; HASTE = half-Fourier acquisition single-shot turbo spin echo; MRI = magnetic resonance imaging.

however, studies have shown that they improve sensitivity for detection of bone lesions,[10] and hence the inclusion of postcontrast imaging in our WBMRI protocol. This study demonstrates that both DWI and CE T1-W imaging increased diagnostic confidence in characterization of incidental findings.

Nevertheless, there are limitations to this study. Incidental findings were recorded regardless of clinical importance, so our detection rate is likely to exceed that of a typical clinical report. Second, because our study was retrospective in nature, it was not possible to determine if further investigation of indeterminate findings had resulted in action in all patients, even after electronic patient record review. However, of the 7 cases identified, only 2 were considered to be of moderate clinical significance by clinical consensus. Additionally, only one reader performed the imaging analysis, so intra- and interobserver variation could not be assessed. It is also theoretically possible that additional incidental findings could be demonstrated on supplementary sequences such as CE T1-W sequences (eg, hypervascular hepatosplenic lesions); however, this potential issue was not encountered in our study cohort. Finally, the grading score used to assess malignancy likelihood of indeterminate findings has not been validated for use in previous studies. This study could be further improved by incorporating a second reader and using a prospective approach.

Table 4 Clinical Consensus of Significance of Indeterminate Findings

Patient No.	Indeterminate Finding	Further Investigation Advised	Investigated	Clinical Significance[a]
1	5 mm subpleural lung lesion	CT chest follow-up as per British Thoracic Society guidelines	N	Low
2	7 mm liver lesion	Dedicated hepatic MRI	N	Low
3	10 mm subpleural lung lesion	CT chest follow-up as per British Thoracic Society guidelines	N	Low
4	Endometrial thickening	Clinical correlation with or without pelvic US	N	Moderate
5	Adnexal lesion	Correlation with previous imaging and pelvic US	N	Low
6	Prostate lesion	Correlation with PSA with or without histology	N	Moderate
7	SCF and cervical nodes	Clinical correlation with or without FNA suggested	N	Low

Abbreviations: CT = computed tomography; FNA = fine needle aspiration; MRI = magnetic resonance imaging; PSA = prostate-specific antigen; SCF = supraclavicular fossa; US = ultrasound.
[a]Low or moderate indicates meriting further routine investigation; high, meriting urgent investigation.

Conclusion

Incidental findings are relatively common in patients with plasma-cell disorders undergoing WBMRI. The majority of findings are benign in nature and can be characterized fully with a comprehensive protocol, necessitating few additional investigations. Our findings should provide reassurance to clinicians requesting WBMRI.

Clinical Practice Points

- There has only been one previous study assessing the frequency and significance of incidental findings at WBMRI in myeloma, in which incidental findings were detected in 38% of patients. In our study, the detection rate was significantly higher (97%). This difference may be explained by differences in imaging protocol and by variations in individual radiologist thresholds for reporting some incidental findings.
- The results of this study demonstrate that although incidental findings are common at WBMRI, most are not clinically significant. The inclusion of contrast-enhanced and DWI sequences in WBMRI protocols substantially improves reader confidence in characterization of incidental findings, thus reducing the need for further additional investigations (potentially resulting in patient anxiety and additional health care costs).
- Our results should provide reassurance to clinicians requesting WBMRI with regard to possible incidental findings, and should provide further evidence to support the inclusion of contrast-enhanced and DWI sequences in WBMRI protocols additional to their value in detection of bone disease in myeloma.

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Disclosure

The authors have stated that they have no conflict of interest.

References

1. Rajkumar SV, Dimopoulos SA, Palumbo A, et al. International Myeloma Working Group updated criteria for the diagnosis of myeloma. *Lancet Oncol* 2014; 15:e538-48.
2. National Institute for Health and Care Excellence. Myeloma: diagnosis and management. NICE guideline [NG35], Available at: https://www.nice.org.uk/guidance/ng35 February 2016. Accessed: August 21, 2018.
3. Chantry A, Kazmi M, Barrington S, et al. Guidelines for the use of imaging in the management of patients with myeloma. *Br J Haematol* 2017; 178:380-93.
4. Hegenscheid K, Seipel R, Schmidt CO, et al. Potentially relevant incidental findings on research whole body MRI in the general adult population: frequencies and management. *Eur Radiol* 2013; 23:816-26.
5. Galia M, Albano D, Narese D, et al. Whole-body MRI in patients with lymphoma: collateral findings. *Radiol Med* 2016; 121:793-800.
6. Jeremko JL, MacMahon PJ, Torriani M, et al. Whole-body MRI in neurofibromatosis: incidental findings and prevalence of scoliosis. *Skeletal Radiol* 2012; 41:917-23.
7. Wale A, Pawlyn C, Kaiser M, Messiou C. Frequency, distribution and clinical management of incidental findings and extramedullary plasmacytomas in whole body diffusion weighted magnetic resonance imaging in patients with multiple myeloma. *Haematologica* 2016; 101:e142-4.
8. Hillengass J, Bäuerle T, Bartl R, et al. Diffusion-weighted imaging for non invasive and quantitative monitoring of bone marrow infiltration in patients with monoclonal plasma cell disease: a comparative study with histology. *Br J Haematol* 2011; 153:721-8.
9. Giles SL, Messiou C, Collins DJ, et al. Whole-body diffusion-weighted MR imaging for assessment of treatment response in myeloma. *Radiology* 2014; 271:785-94.
10. Dutoit JC, Vanderkerken MA, Verstraete KL. Value of whole body MRI and dynamic contrast-enhanced MRI in the diagnosis, follow-up and evaluation of disease activity and extent in multiple myeloma. *Eur J Radiol* 2013; 82:1444-52.