WHOLE-BODY PET-MR INCLUDING DWI, T2W, AND GADOFOSVESET-ENHANCED T1W SEQUENCES: EVALUATION OF MR PERFORMANCE COMPARED TO PET-CT AND RELATIVE BENEFITS PROVIDED BY EACH SEQUENCE

Piotr Obara[1], Andreas Loening[1], Valentina Taviani[1], Andrei Iagaru[1], Brian Hargreaves[1], and Shreyas Vasanawala[1]
[1]*Radiology, Stanford Hospital, Stanford, California, United States*

Target audience: Clinicians with an interest in PET-MR and whole-body MRI.

Purpose: Whole body PET-MR is an emerging technique offering potential benefits in oncologic imaging[1]. Currently, no consensus exists regarding the optimal MR protocol for PET-MR. Also, there is little data regarding the use of gadofosveset for oncologic and whole body imaging[2]. The purpose of this study was to evaluate three MR sequences, coronal Diffusion Weighted Imaging (DWI), fat saturated T2-weighted (T2w) Single-Shot Fast Spin Echo (SSFSE), and gadofosveset -enhanced T1-weighted (T1w) two-point Dixon SPGR, in comparison to each other and to PET in their ability to identify malignant lesions.

Methods: *Imaging protocol:* Under IRB approval, 14 patients with history of malignancy underwent same day PET-CT (GE Discovery 600 or 690, GE Healthcare, Waukesha, WI) and PET-MR (GE Signa) exams with a single 10mCi injection of 18F FDG administered immediately before the PET-CT portion of the study. PET/CT scans were acquired in 3D mode using a standard clinical protocol. PET-MR was performed approximately 2 hours after PET-CT. The MR portion of the exam included stations of coronal DWI, coronal T2w SSFSE with Adiabatic Spectral Inversion Recovery preparation (TE=1.4s, TR=100ms, TI=170ms, 0.5 NEX, slice thickness = 8mm, matrix size = 320x224), and gadofosveset-enhanced (Ablavar®, Lantheus Medical, North Billerica, MA; 0.12ml/kg up to 10ml) 3D 2-point Dixon T1w SPGR (TE1/TE2 = 1.1/2.3ms, TR = 5ms, flip angle = 15°, 0.7 NEX, slice thickness = 3.4mm, matrix size = 388x388) with reconstruction of water-only, fat-only, and in- and opposed-phase images. Coronal DWI was performed using a custom-developed 2D Single-Shot Echo Planar Imaging (SS-EPI) pulse sequence with 2D excitation[3] to allow S/I phase encoding (TE=61s, TR=2.5s, b = 50 [8 NEX] and 800 [16 NEX] s/mm^2, slice thickness = 8mm, phase FOV = 0.55, matrix size = 160x160, parallel imaging factor = 2). A 44cm FOV was used for all sequences at each station.

Image evaluation: For each patient, image sets consisting of DWI, T2w and post-contrast T1w including all four reconstructions (T1w+C), covering stations 1 to 6 (head vertex to lower thigh), were independently evaluated by two readers. For each sequence and the entire image set, a confidence score was assigned to each organ (19 per patient) based on the reader's confidence of presence or absence of malignancy (1=definitely benign, 2=probably benign, 3=equivocal, 4=probably malignant, 5=definitely malignant). Conspicuity and delineation of suspicious lesions on each sequence were scored on a 4-point scale (1=poor, 2=fair, 3=good, 4=excellent). MR findings were compared to clinical PET-CT report findings, taken as the gold standard. A confidence score of 1 or 2 was considered absence of disease; score of 4 or 5 was considered presence of disease; score of 3 was treated as absence of disease if no lesions were identified and as presence of disease if equivocal lesions were found. Conspicuity and delineation score differences were assessed for statistical significance with Wilcoxon sign rank test. Weighed kappa was used to determine inter-observer agreement of confidence scores.

Results and discussion: A total of 25 organs in 7 patients were affected by disease. MR showed good sensitivity on both a per-patient and per-organ basis. Specificity was high on a per-organ basis, however, it was only fair on a per-patient basis (Table 1). False negatives involved findings in the pelvic organs (cervix and rectum) and lungs. Organs where falsely positive or equivocal findings were detected included the skull (2), cervical spine (3), thoracic spine (2), lungs (2), adrenal gland (2), mediastinum (1), pelvic bones (2), femurs (2), and pelvic and retroperitoneal lymph nodes (2). Confidence scores based on all MR image sets showed very good inter-reader agreement (weighed kappa=0.85).

		Reader 1				Reader 2			
Sequence		DWI	T2w	T1wC	All	DWI	T2w	T1wC	All
Sensitivity (%)	Per-patient	71.4	71.4	85.6	85.7	71.4	71.4	85.7	85.7
	Per-organ	92.0	84.0	92.0	92.3	84.0	72.0	88.0	96.7
Specificity (%)	Per-patient	57.1	57.1	71.4	57.1	71.4	71.4	85.7	71.4
	Per-organ	96.2	96.7	95.9	95.4	96.3	98.3	97.1	96.7

Table 1. MR performance compared to PET-CT.

Lesion conspicuity was highest on DWI (Figure 1), with a significant difference compared to T2w (p<0.05) for both readers and nearly significant difference compared to T1w+C (reader 1, 2: p=0.06, p=0.08, respectively). No significant difference in conspicuity was seen between T2w and T1w+C. The higher conspicuity on DWI vs. T2w and T1w+C was most notable for osseous structures (Figure 2, 3). The average combined conspicuity of lesions in the thoracic/lumbar spine, pelvic bones, and femurs on DWI, T2w, and T1w+C was rated as 3.7, 2.9, 2.7, respectively (statistical significance could not be accurately determined given small sample size). Both readers noted suboptimal enhancement of lesions on T1w+C images, particularly in lungs and osseous structures; in osseous structures conspicuity on fat-only images was superior to water-only images (Figures 2, 3). Lesion delineation was rated lowest on T2w images and highest on T1w+C (Figure 1), with a significant difference in rating between these sequences by both readers (p<0.05). Confidence of excluding disease was on average highest on T1w+C and lowest on DWI (T1w+C: 1.4, T2w: 2.1, DWI: 2.4). The lowest average confidence of excluding disease was on DW images of the mediastinum, lungs (Figure 4), and bowel (confidence scores of 2.2, 2, 1.9, respectively). On T2w, confidence was lowest in the mediastinum (1.8) and lungs (1.6). On T1w+C, confidence was lowest for lungs (1.4).

Conclusion: Whole-body MR imaging using gadofosveset showed good sensitivity but only fair specificity on a per-patient basis, which was largely due to false positive findings in osseous structures. Sensitivity was lowest on T2w and highest on T1w+C images. Lesion conspicuity was highest on DWI, particularly in bone. The lower conspicuity on post-contrast images with gadofosveset may be in part due to the observed suboptimal lesion enhancement with this agent, which emphasizes evaluation of fat-only images.

.

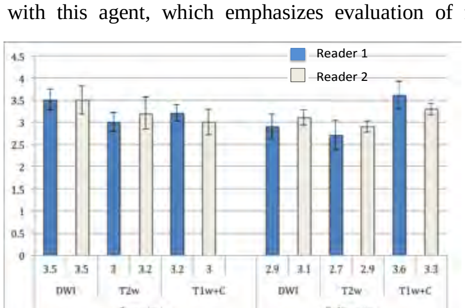

Figure 1. Ratings of lesion conspicuity and delineation.

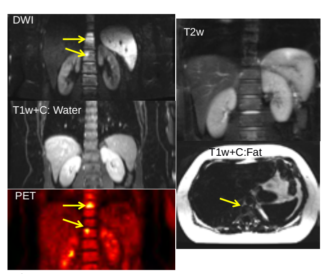

Figure 2. Spine metastases most conspicuous on DWI and relatively inconspicuous on T2w and T1w+C water images.

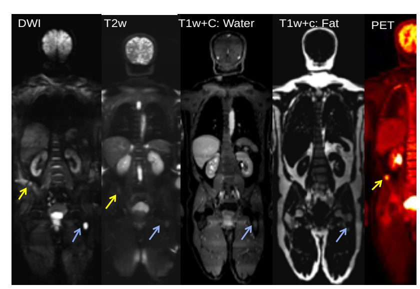

Figure 3. Metastatic lesions in the right iliac bone (yellow) and left femur (blue) are best depicted on DWI.

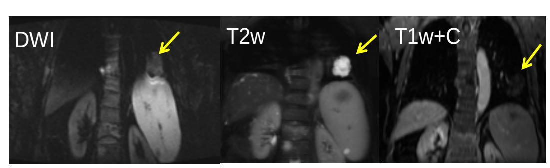

Figure 4. Higher conspicuity of lung lesion on T2w compared to DWI and T1+C.

References: [1] Eiber M. et al, JNM 2014; p 191; [2] Heijnen LA. et al, Eur Radiol 2014; p 371; [3] Fung M.M. et al, ISMRM 2014, p.2238

Acknowledgement: GE Healthcare. Stanford University Lucas Center

Disclaimer: Data acquired using an investigational device that is 510k pending at