European Journal of Radiology 81 (2012) 1917–1925

Contents lists available at SciVerse ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Role of combined DWIBS/3D-CE-T1w whole-body MRI in tumor staging: Comparison with PET-CT

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ARTICLE INFO

Article history:
Received 25 April 2011
Received in revised form 7 August 2011
Accepted 8 August 2011

Keywords:
Whole-body magnetic resonance imaging (WB-MRI)
Diffusion weighted imaging (DWI)
Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS)
Positron emission tomography-computed tomography (PET-CT)
Cancer staging

ABSTRACT

Objectives: To assess the diagnostic performance of whole-body magnetic resonance imaging (WB-MRI) by diffusion-weighted whole-body imaging with background body signal suppression (DWIBS) in malignant tumor detection and the potential diagnostic advantages in generating fused DWIBS/3D-contrast enhanced T1w (3D-CE-T1w) images.
Methods: 45 cancer patients underwent 18F-FDG PET-CT and WB-MRI for staging purpose. Fused DWIBS/3D-CE T1w images were generated off-line. 3D-CE-T1w, DWIBS images alone and fused with 3D-CE T1w were compared by two readers groups for detection of primary diseases and local/distant metastases. Diagnostic performance between the three WB-MRI data sets was assessed using receiver operating characteristic (ROC) curve analysis. Imaging exams and histopathological results were used as standard of references.
Results: Areas under the ROC curves of DWIBS vs. 3D-CE-T1w vs. both sequences in fused fashion were 0.97, 0.978, and 1.00, respectively. The diagnostic performance in tumor detection of fused DWIBS/3D-CE-T1w images were statistically superior to DWIBS ($p < 0.001$) and 3D-CE-T1w ($p \leq 0.002$); while the difference between DWIBS and 3D-CE-T1w did not show statistical significance difference. Detection rates of malignancy did not differ between WB-MRI with DWIBS and 18F-FDG PET-CT.
Conclusion: WB-MRI with DWIBS is to be considered as alternative tool to conventional whole-body methods for tumor staging and during follow-up in cancer patients.

1. Introduction

Local and distant tumor staging have a pivotal role for therapeutic option and prognosis of oncologic diseases. As tumor spread may involve different anatomical regions, accurate whole-body evaluation requires common multimodality approach, including conventional radiography, ultrasonography (US), computed tomography (CT), scintigraphy and positron emission tomography (PET).

Over the last decade, positron emission tomography (PET) with 2-deoxy-2 [F] fluoro-D-glucose (FDG) in combination with CT (PET-CT) has become an important non-invasive imaging modality for the preoperative staging of various tumors. Metabolic information, provided with PET exam, is combined to anatomical data of CT scan, resulting in higher diagnostic accuracy compared with the two imaging modalities alone and with both imaging modalities viewed side-by-side [1].

Whole-body magnetic resonance imaging (WB-MRI), with its lack of ionizing radiation, but high contrast and spatial resolution, is a promising whole body imaging tool for detection and staging of various neoplastic diseases, especially for tumors frequently metastasizing to the abdominal organs, bone, brain (e.g. lung, breast, colorectal, prostate cancers) or for haematologic diseases with nodal or bone marrow involvement [2].

Up-to-date, WB-MRI provided mainly morphological information on tumor spread; however, the lack of functional informations has been overcome by the introduction in clinical practice of diffusion whole body imaging. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS) is a newly diagnostic sequence, introduced in recent years in WB-MRI protocols [3]. DWIBS provides functional data about tumor cellularity and has

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doi:10.1016/j.ejrad.2011.08.005

Table 1
Patient characteristics.

Male	24
Female	21
Age (range)	66 (48–79)
Tumor histopatology	
Colo-rectal cancer (CRC)	10
Lung cancer (LC)	7
Hodgkin lymphoma (HL)	9
Multiple myeloma (MM)	10
Breast cancer (BC)	9
Diagnosed lesions	
Adrenal metastases	3
Bone lesions in multiple myeloma patients	39
Bone metastases	32
Brain metastases	5
Breast cancer	4
Liver metastases	29
Colo-rectal cancer	3
Lymph nodes metastases	54
Lung metastases	22
Extra-medullary disease in multiple myeloma patients	5
Bulky mass	6
Other findings	
Pancreatic cysts	5
Liver cysts	29
Hepatic haemangiomas	21
Lymp nodes	26
Renal cysts	32
Vertebral haemangiomas	13
Osteoporotic vertebrae fracture	1
Ovarian cysts	7
Splenic haemangioma	1

been found to be of complementary value to morphological imaging studies when assessing lymph node involvement or distant metastasis [4]. With DWIBS, tumor sites may be detected throughout the entire body with high contrast resolution; however, exact localization of lesions with DWIBS may be less accurate due to its relatively low spatial resolution and lack of anatomical reference because most normal anatomic structures signal is suppressed [5,6].

These drawbacks may be overcome by combining DWIBS with 3D fat suppressed contrast enhanced T1 weighted MR imaging (3D-CE-T1W; e.g. T1-weighted high-resolution isotropic volume examination, THRIVE) to provide anatomical information and to differentiate malignant from normal tissue.

The aim of our study is to retrospectively assess the diagnostic performance of DWIBS, WB-MRI and fused DWIBS/3D-CE-T1w images for malignant tumor detection and to evaluate if there is an additional value in generating fusion images of DWIBS and 3D contrast-enhanced images.

2. Materials and methods

2.1. Subjects

This study was performed after approval of the local institutional review board. Written informed consent was obtained from all participants. A total of 45 consecutive patients (24 male and 21 female; mean age of 66 years; range 48–79) with diagnosis of malignant disease were included in the study. Primary tumors included 7 lung carcinoma (LC), 9 Hodgkin's lymphoma (HL), 10 colo-rectal cancers (CRC), 10 multiple myeloma (MM), 9 breast cancer (BC) (Table 1). All patients were submitted to 18F-FDG-PET-CT for staging purpose, according to our institutional guidelines. Histopathological specimens were used as standard of reference for primary tumors in all cases. Imaging follow-up at 12 months and histopathological results, where available, were used as a gold standard.

2.2. MR imaging

WB-MRI was performed with a 3.0 Tesla MR scanner (Achieva, Philips Healthcare, 80 mT/m maximum amplitude, 0.16 ms minimal rise time, 200 T/m/s maximum slew rate) with patient in supine feet-first position, covering the entire body as a matrix with a maximal longitudinal field of view (FOV) of 200 cm, in combination with automated table movement. Whole-body images were obtained with multiple stacks acquisitions (7 or 8 overlapped stacks depending on body height, as follow: head/neck, thorax, abdomen, pelvis, thighs, knees and calves), using Q-body coil for signal receiving and transmitting. Our standard whole-body MR imaging protocol consisted of unenhanced T1-weighted and T2-weighted turbo field-echo (TFE), DWIBS sequences and 3D-CE-T1W sequences (THRIVE) (parameters in Table 2).

DWIBS images were acquired using single-shot echo-planar imaging (EPI) sequences with a short inversion time inversion recovery (STIR) pre-pulse for fat suppression. 60 slices each stack (*n*. 4: head/neck; thorax; abdomen; pelvis) were obtained using free-breathing technique on axial plane; motion probing gradients (MPGs) in three orthogonal axes were applied for two *b* value 0 and 1000 s/mm^2, with 6 signal sampling average. Gadolinium-enhanced isotropic three-dimensional T1-weighted high-resolution isotropic volume acquisition with fat suppression (3D-CE-T1w; THRIVE) imaging was performed on axial plane before and after administration of a paramagnetic contrast agent (0.2 mmol/kg gadopentetate dimeglumine, Magnevist; Bayer-Schering, Berlin, Germany), injected into the antecubital vein (3 ml/s flow rate) followed by 20 ml saline solution using an automated injector (Spectris MR, Medrad Europe). After i.v. administration of a paramagnetic contrast agent (0.1 mmol/kg of gadolinium), 3D data sets of the abdomen were acquired in axial plane in the early arterial and portal venous phases. Subsequently, the rolling table platform was moved to the skull, thorax, abdomen, pelvis and femur to acquire data sets in coronal plane during equilibrium contrast phase. Total acquisition time for whole-body MRI was less than 60 min.

2.3. 18F-FDG-PET-CT

All examinations were performed with an integrated PET/CT scanner, Discovery ST (GE, General Electric Medical Systems, Milwaukee, WI, USA). The system combines a high speed ultra 16-detector-row CT scanner with a PET scanner equipped with 10080 bismuth germinate crystals arranged in 24 rings. Patients were required to fast for at least 6 h prior to the examination

A baseline CT scan with low tube current (80 mA) was then acquired to correct the attenuation for the PET study. The following scan parameters were used: 140 kV to obtain good quality images at the level of the shoulder and pelvic girdles; 80 mA; FOV 420–500 mm; CT slice thickness 3.75 mm (retrospectively reconstructed to 1.25 mm) to approximate the width of the PET section; slice interval 3.27 mm, to coincide with the spacing between the PET sections; scan speed <1 s per revolution. Once the CT scan was completed, the PET scan was performed with a 2D technique in the caudo-cranial direction from the proximal third of the femurs to the head; five to six bed positions were acquired, with duration time of 4 min per bed. Images were reconstructed using a standard iterative algorithm [ordered subsets expectation maximisation (OSEM)], with a mean duration of 20–24 min for the PET examination. PET acquisition was immediately followed by CT examination performed with the intravenous administration of 100–120 ml of non-ionic iodinated contrast medium with injection rate of 2–3 ml/s (Iomeron 350 mgI/ml, Bracco, Milan, Italy). Two data sets were acquired: the first included the upper abdomen with a delay of 30 s from the beginning of the contrast injection, and the