Diffusion-Weighted Whole-Body Imaging with Background Body Signal Suppression (DWIBS): MRI Sequence for Metastatic Workup

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Abstract

Objectives: To assess the feasibility of DWIBS in screening patients for metastasis either in bone, solid organs or lymph nodes.

Patients and Methods: A total of 50 patients (27 men and 23 women) with their ages ranged from 27-69 years, mean age, 48 years. Forty five patients (25 men and 20 women) had distant metastases from a known primary malignancy, and five patients (2 men and 3 women) had no known primary malignancy. All of them underwent DWIBS, whole body T1WI and STIR reconstructed in the coronal plane and also whole body T2WI for only ten patients.

Results: Distant metastases were well depicted in lymph nodes, solid organs or bone marrow in T1WI, T2WI & STIR images and DWIBS but the later detected more bone marrow lesions than those detected in the former MRI sequences in only two patients. In the patients not known to have primary malignancy; abnormal bone marrow infiltration was depicted in DWIBS and was proved to be lymphoma. In another patient; a right breast mass was detected in DWIBS and was histo-pathologically proved as ductal adenocarcinoma. DWIBS and other conventional pulse sequences depicted recurrent tumors as well as distant metastases; however the conventional pulse sequences localized the lesions better. A high degree of agreement also existed between DWIBS and STIR more than other pulse sequences.

Conclusion: DWIBS satisfactorily shows the presence and the extent of bone as well soft tissue (solid organs and lymph nodes) metastases but not specific for the characterization of lesions. It needs no ionizing radiation or contrast media and also has better spatial resolution. The relative availability of this technique and local experience should first be taken into account.

Key Words: MRI—DWIBS.

Introduction

Imaging plays a pivotal role in cancer staging. Furthermore, imaging is of great importance in monitoring response to therapy and in the detection of tumor recurrence ill.

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Whole body imaging to detect the presence, site, size and the number of bone as well as soft tissue metastases, is vital for deciding the management in oncology. Bone scans or PET-CT scans are widely used for this purpose. But as the oncology patients are already weakened, not only by the disease entity itself, but also by chemotherapy, there is a possibility that the exorbitant diagnostic radiation which is involved in the bone scans or the PET-CT scans may turn out to be the proverbial last straw on the camel’s back. It is noteworthy that MRI can detect bone metastases even before they manifest on the bone scan [2].

DWI using single-shot echo-planar imaging (EPI) is a well established method to examine the brain. Extracranial DWI, however, did not become a clinical standard because the use of EPI was complicated by magnetic susceptibility artifacts and severe image distortion in the body [3,4]. Recently introduced parallel imaging techniques, such as sensitivity encoding (SENSE) [5,6], and the development of stronger gradients and multi-channel coils have largely overcome this problem; DWI of adequate quality can now be performed in the body, at high p-value [7,8]. Despite, the above-mentioned breakthroughs in DWI, breath hold or respiratory triggered scanning was still considered necessary since it was widely accepted that respiratory motion was an impediment for DWI of (moving) visceral organs [9-11].

The DWIBS technique intentionally uses free breathing scanning rather than breathholding or respiratory triggering to visualize (moving) visceral organs and their lesions. Ballon et al. [12] reported whole-body DWI during free breathing, this study aimed to visualize metastatic lesions in static tissue (bone marrow), however, they additionally found that visceral organs, such as the spleen and kidneys, were also visualized. The feasibility of the free
breathing approach could initially not be explained, but was clarified later; it can be understood with knowledge of the relationship between the motion probing gradients (MPGs) and the type (coherence) of motion. This concept offers a wide range of potential applications in whole-body oncological imaging.

However, it is difficult to obtain PET like three-dimensional images with a large field of view because of two major limitations. One of the limitations is the brief scan time, which leads to poor image quality. As diffusion weighted imaging (DWI), theoretically, aims to detect motion over very small distances, such as Brownian motion, breath hold scan has been considered the only way to avoid the artifacts from the bulk motion of subjects. The limitation of scan time by breath hold does not permit thin slice DWI with adequate signal-to-noise ratio (SNR) and multiple excitations that can be used as source images of three-dimensional display. The other limitation is insufficient fat suppression when using the usual combination of the spin echo-echo planar imaging (SE-EPI) sequence and chemical shift selective (CHESS) technique. When displayed in 2D, insufficient fat suppression that appears in the peripheral portions of the image do not have a severe effect on image interpretation and does not hamper the diagnosis. However, in 3D display, residual fat signal in the periphery of the subject will be superimposed on the central portions of the body, possibly obscuring important lesions inside the body. A new way to obtain multiple thin slices DWI using a free breathing approach that affords multiple slice excitations and signal averaging over an extended period of time, and a short TI inversion recovery (STIR)-EPI sequence that allows potent fat suppression, which may improve the quality of the 3D reconstructed images in whole body imaging [2].

Aim of the work:
To assess the feasibility of DWIBS in screening patients for metastasis either in bone, solid organs or lymph nodes.

Material and Methods
A total of 50 patients (27 men and 23 women) with their ages ranged from 27-69 years, mean age, 48 years underwent whole body MRI sequences in the period from January 2012 to January 2013. Forty five patients (25 male and 20 female) suspected to have distant metastases from a known malignant primary neoplasm (18 patients were with breast cancer, 8 patients colorectal cancer, 14 patients with lymphoma and 5 patients with head and neck malignancies) and five patients not known to have primary malignancy and complaining from bone pain were included in this study.

Inclusion and exclusion criteria
Inclusion criteria:
• Patients with known malignant primary neoplasm and suspected osseous, nodal, or solid organ metastases.
• Patients with malignant bone marrow tumors or pathological fractures.
• Patients with metastases of unknown primary.

Exclusion criteria:
• Patients who have a heart pacemaker.
• Patients who have a metallic foreign body in their eye, or who have an aneurysm clip in their brain, cannot have an MRI scan since the magnetic field may dislodge the metal.
• Patients with severe claustrophobia may not be able to tolerate an MRI scan.
• Patients who have had metallic devices placed in their back (such as pedicle screws or anterior interbody cages) can have an MRI scan, but the resolution of the scan is often severely hampered by the metal device and the spine is not well imaged.

Patient preparation:
• No special preparation, food or fluid restrictions were needed.
• Any metallic object was removed before performing MRI; detachable metallic implants like teeth prostheses were considered proportional contraindications that should be removed.
• No need for contrast administration.

Technique:
Imaging protocol:
All scans were performed on a 1.5 Tesla Achieva MRI machine (gradient strength= 33 mT/m, slew rate= 122 T/m/s, Philips Medical system, Netherlands), after informed written consent was obtained from the patients prior to the study. We use the SENSE parallel imaging technique in axial image with 6 stacks using Q body and Torso coils that reconstructed in coronal view in following parameters; (>6600/ <70ms ms, with a 4-mm section thickness, 0mm interval, 180x160mm field of view, 256x512 pixel matrix, SENCE factor 2, EPI 47, p-value 1000sec/mm, No breath hold were required).

The resulting DWIBS images were displayed by using black and white inverse gray scales, in
order to be comparable with that of PET-CT and bone scan images.

T1WI, T2WI and STIR images were also done in coronal planes for each patient with free breathing technique and T2WI for only some patients.

**Image assessment:**

The MRI findings were assessed independently by two radiologists. They had access to only the clinical history.

The criteria for the solid organ (lung, liver, spleen, pancreas, kidney, suprarenal, bowel loops) and bone marrow focal lesions were abnormal signal intensity seen as low signal on T1WI and hypersignal on T2WI, STIR and DWIBS.

The criteria for pathological lymph node involvement were the same signal abnormality as the previously described lesions in addition to the size (positive when more than 1 cm) or forming mass lesion.

Results

All patients were subjected to MRI examination in the form of whole body T1WI, STIR and DWIBS sequences and T2WI in only ten patients.

All the images were technically appropriate, and no technique-related complications were observed. All the images presented a good quality, despite the presence of artifacts, not affecting the diagnostic outcome. Such artifacts occurred predominantly in the chest and abdomen, and were caused by breathing, heartbeats and/or body motion.

In all patients with known primary malignancy, the distant metastases were well depicted in lymph nodes, solid organs or bone marrow in T1WI, T2WI, STIR images and DWIBS but the latter detected more bone marrow lesions than those detected in the former MRI sequences in two patients (Fig. 1) and Table (1).

![Fig. (1): A known case of prostatic cancer with multiple bone marrow deposits and iliac lymphadenopathy as seen in (a) coronal T1WI, (b) STIR and (c) DWIBS, but the bone marrow deposits are more numerous in DWIBS and STIR "the D12 bone deposit is not seen on T1WI", while the enlarged LNs are seen similar in all sequences. The enlarged prostate with a focal lesion is depicted only on STIR.](image-url)
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Fig. (2): A patient with no known primary neoplasm, (a) and (b) T1WI, (c), (d) and (e) STIR, (f), (g) and (h) DWIBS images show multiple bone metastatic deposits and right axillary (open arrow), infraclavicular & right paratracheal as well as bilateral hilar adenopathy. A right breast mass (arrow) is depicted and histologically proved as ductal adenocarcinoma.

Fig. (3): A patient presented by generalized bone pain. DWIBS showed abnormal diffuse marrow infiltration and histologically proved as lymphomatous infiltration.
Fig. (4): A patient with recurrent right breast cancer and edematous left breast showing multiple hepatic, bone and pulmonary metastases as well as right sided pleural effusion.
Fig. (5): A patient with cancer bladder and bilateral pelvic LNs and bony metastatic lesions (a), (b) T1W, (c), (d), (e) STIR, (f), (g), (h) DWIBS, the extension of the left iliac LNs and lumbar and dorsal vertebral deposits are comparable in both DWIBS and STIR but to a lesser extent in T1WI.
Table (1): No. of metastatic lesions depicted in all MRI pulse sequences.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>No. of Metastatic deposits</th>
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<tbody>
<tr>
<td></td>
<td>Bone Mets</td>
</tr>
<tr>
<td>T1W</td>
<td>88</td>
</tr>
<tr>
<td>STIR</td>
<td>87</td>
</tr>
<tr>
<td>DWIBS</td>
<td>92</td>
</tr>
</tbody>
</table>

In five patients not known to have primary malignancy, the primary tumor was depicted in a patient in whole body MRI sequences and it was ductal adenocarcinoma of the right breast and the secondaries affecting the bone marrow were more numerous in DWIBS than other conventional MRI sequences (Fig. 2) (Table 1). In another patient of this group, DWIBS showed abnormal marrow signal that warranted bone marrow biopsy and was histopathologically proved as lymphomatous infiltration (Fig. 3) (Table 1).

Among fifteen patients with known primary malignancy (surgically resected); MR imaging in addition to depicting distant metastases, recurrent tumors were depicted in five patients (one patient had rectal cancer, another had urinary bladder cancer and the other three patients had breast cancer) (Fig. 4).

High degree of agreement existed between DWIBS and STIR than DWIBS and other conventional MRI sequences. However, the number of lesions in each case depicted in DWIBS was higher than those depicted in other sequences, the conventional MRI sequences more accurately localized these lesions (Fig. 5).

Discussion

Although DWIBS offers many potential applications in oncological imaging, it may suffer from several drawbacks. First, DWIBS does not exclusively visualize malignant tumors. Benign pathologies with restricted diffusion, such as abscesses, will also exhibit high signal on DWIBS source images [13]. Furthermore, DWIBS not only visualizes pathological areas of restricted diffusion, but also several normal structures; brain, salivary glands, tonsils, spleen, gallbladder, small intestine/small intestinal contents, prostate, testes, penis, spinal cord, peripheral nerves, lymph nodes and bone marrow may all exhibit high signal intensity on DWIBS source images. High signal intensities within these organs do not necessarily indicate pathologic states, whereas true lesions within these organs may be obscured. Although at the expense of prolonged acquisition time, T2 shine-through effects can be removed by performing ADC mapping, provided that ADC mapping is accurate and feasible in DWIBS. Another limitation of DWIBS is its suppression of background body signals, as a result of which sufficient anatomical information is lacking. Standard T1- and T2-weighted sequences therefore remain indispensable to act as an anatomical reference frame for the DWIBS images, in order to exactly localize lesions. DWIBS and anatomical (whole-body) MRI can be viewed side-by-side, or fused with commercially available software (Mobiview in Philips systems). An additional advantage of DWIBS/anatomical MRI fusion may be increased sensitivity and specificity. Finally, although DWIBS images can be post-processed to create MIPs and PET-like images, which are very attractive for demonstration purposes, source images should always be consulted, because subtle lesions may be missed or obscured in projected images [14].

Whole-body MRI has an advantage of having no ionizing radiation that may increase the risk for secondary neoplasia especially in children [15-17]. Additionally, there is no need for either oral or intravenous administration of contrast agents.

Although previous studies report the higher sensitivity of diffusion-weighted MRI in the detection of metastases and in the monitoring of the response to chemotherapy, significant differences were not observed in the present study with respect to the STIR sequence as that reported by Nava et al. [18].

At MRI, alteration of the signal intensity and/or lesion size is utilized as diagnostic criterion for the presence of tumor activity. On the other hand, PET-CT evaluates the tumor metabolism based on the increase in the glycolytic activity. As both diagnostic methods are utilized in the staging and follow-up of oncologic patients [18].

ADC measurements in DWIBS signal intensity is directly related to the degree of diffusion and the ADC is the quantitative measure of diffusion in DWI. Both signal intensity and ADCs are mainstays in the identification and characterization of lesions in DWI. However, because of the allowance of respiratory motion in DWIBS, slice levels of images obtained with different p-values may not be identical. In addition, because DWIBS employs multiple slice excitations, slices levels of images obtained with the same p-value may be different. Consequently, ADC measurements of moving organs in DWIBS may be less accurate, less repro-
ducible, and different from conventional (breath-hold or respiratory triggered) DWI. In other words, DWIBS images of moving organs are possibly more suitable for visual non-quantitative evaluation than quantitative analysis [91]. Also, it should be noted that the comparison between respiratory triggered DWI and DWIBS was (clinically) not fair, since roughly estimated scanning time of respiratory triggered DWI was approximately 1.3- to 2-times longer [20].

Our study is retrospective and concern with assessment of DWIBS ability in detection of metastases as done by Sushil G. Kashewar et al., (2011) [21] and we reported comparable results.

Also Cheng, et al. [22], study the ability of DWIBS in detection of metastatic deposits in various location concerning bone, LN and solid organs and concluded a little pit different result that in our study as ability of conventional MRI sequence and/or CT to detected osteoplastic metastases, mediastinal LNs and lung and brain metastases better than WB-DWI and also their ability to differentiate benign from malignant liver focuses.

Many studies compare the DWIBS with PET-CT in detection and staging of cancer patients as well as follow-up after surgery or therapy. Of these studies Gu et al., [23] that concluded that DWIBS provides satisfactory diagnostic accuracy in lymphoma compared with PET/CT, and B. Goudarzi et al., [24] that concluded that DWIBS is superior to MET-PET and bone scan in detection of bone metastases especially in pelvic cavity with the advantage of no ionizing radiation. Also, they concluded that addition T1-weighted and T2-weighted MRI together with DWIBS should improve accuracy as we done in our study. While Squillaci et al. [25], concluded that WB-MRI is an effective and fast method for staging colon/rectal cancer patients but can not reach the accuracy of PET-CT.

Conclusion:

DWIBS is an effective method for detection of solid organs, bone and lymph node metastasis but not specific for characterization of lesions. Results indicate that it shows excellent diagnostic accuracy for the detection of distant metastatic disease and represents a promising tool for tumor surveillance and screening of patient populations with suspicion of tumor recurrence, especially in tumors with frequent metastatic spread to the bone, liver or CNS. As a whole-body bone marrow screening method it is a useful tool for a precise assessment of the total skeletal status and is highly effective in staging specific malignant bone marrow diseases, such as multiple myeloma, lymphoma or early bone metastasis. Therefore, patients might benefit from early accurate staging and improved therapeutic options.

It needs no ionizing radiation or contrast media and also has better spatial resolution.

The relative availability of this technique and local experience should first be taken into account.

References


