Diffusion-Weighted Magnetic Resonance Imaging as a Potential Tool in Differentiation of Vertebral Bone Marrow Lesions

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Abstract

Background: Pathological lesions usually replace normal components of the vertebral bone marrow including benign and malignant lesions, as well as, fractures, inflammatory and degenerative marrow process. DWI is considered to be a potential tool which can help in characterization of different bone marrow lesions by exploiting the structural differences of biologic tissue.

Objective: To evaluate the role of diffusion weighted magnetic resonance imaging (DWI) as a potential tool in differentiation of vertebral bone marrow lesions.

Material and Methods: Forty patients with bone marrow abnormal MRI signal intensity were included in the study and according to MRI finding they were classified to four groups. DWI was performed with b values of 0 and 500s/mm². As well as apparent diffusion coefficient (ADC) values also estimated.

Results: Four cases of malignant collapse displayed high signal intensity on DWIs and low signal intensity on ADC map, however, benign osteoporotic collapse cases (7 cases 17.5%) were hypo intense (3 cases) and iso to hypo intense (4 cases) on DWIs and being hyper intense on ADC. Twelve cases with endplate changes, the eight infectious spondylitis recorded mean ADC value (1.03±0.33x10⁻³mm²/s). The remaining, 4 cases with degenerative changes recorded ADC value (1.76±0.33x10⁻³mm²/s). Another three cases of malignant bone marrow infiltration without collapse were hyperintense on DWIs and hypointense on ADC map. The mean ADC in hemangioma was (1.9±0.33x10⁻³mm²/s) and in ABC (1.93±0.33x10⁻³mm²/s). DW study of 4 cases respond to therapy recorded mean ADC value (1.64±0.33x10⁻³mm²/s), however, the 2 cases with residual viable tumor tissue record (0.79±0.33x10⁻³mm²/s).

Conclusion: DWI with quantitative ADC measurements using b-value (b=500s/mm²) can be good indicator tool in differentiating benign from malignant bone marrow lesions, as well as differentiating between end plate changes causes, also, may be used in post therapy follow-up.

Key Words: Diffusion weighted imaging — Apparent diffusion coefficient — Bone marrow — Vertebral compression fractures — Spondylodiscitis.

Introduction

THE vertebral column is one of most common organs studied using magnetic resonance. Edema in degenerative disease, hemang-iomas, osteoporotic fractures and spondylodiscitis are most common typical bone marrow lesion. Atypical hemangiomas and excessive edema due to degenerative processes can pose problems in the differential diagnosis of malignancy Hi. The most common malignant diseases are metastases, neoplastic vertebral fractures, myeloma, primary malignant bone tumors, lymphoma and leukemia [2].

The differentiation between benign and malignant vertebral collapse represents challenge in elderly patients who are predisposed to benign compression fracture caused by osteoporosis. Benign vertebral fractures occur in approximately 33% of patients having already cancer, and metastatic vertebral fracture account for 39% of bony metastases in patients with primary neoplasm 131.

Bone marrow edema of degenerative disease usually looks as band-like along the end-plates. Sometimes edema may affect the whole vertebral body, thus raising the question of whether a neoplastic process may be present [2].

The cellular structure of a tumor is considered to be an indicator of tumor aggressiveness, and to influence the response to tumor therapy. DWI could be to monitor treatment effects. DWI depicts differences in diffusion and in membrane integrity between viable and necrotic tumor and thus, may be used to monitor tumor viability during treatment [4].

In spite of its high sensitivity, conventional MRI has specificity limitation in the evaluation of
bone marrow alterations, so, these MR-sequences (T1, T2 and STIR) are in general not enough to differentiate between different causes of vertebral abnormal bone marrow signal alteration [9].

DWI is a recent well-established magnetic resonance imaging technique, in which the MRI signal intensity is influenced by self-diffusion, i.e., microscopic stochastic Brownian motion of water molecules caused by the molecular thermal energy. DWI can provide information about the microscopic structure and organization of biological tissue, thus, can detect pathological changes in tissues [6].

DWI technique is a non-invasive investigation for tissue differentiation, while, the apparent diffusion coefficient (ADC) is a quantitative measure of diffusion in diffusion weighted echo-planar imaging (EPI). A hypo intense or iso intense signal was associated with benign edema, whereas, neoplastic process showing hyper intensity in contrast to normal surrounding marrow [6].

Material and Methods

Forty patients were included in this study presented by vertebral collapse and/or altered MR signal intensity in one or more vertebral body on conventional MR. They were 22 males (55%) and 18 females (45%). Their ages ranged from 5 to 70 years and mean age was 49.6 years. All examination were performed on a 1.5T MRI system (Achieva, Philips, Healthcare, Best, The Netherland). This study was done at the Zagzig University Hospital from Jan. 2012 — April 2013.

All patients were subjected to the following:

A- Conventional MRI:
- Sagittal sequence, T1 and T2WIs (600/12 and 5500/120 TR/TE respectively), at 4-mm thickness, 380mm FOV, 258x512 matrix.
- Axial sequence were acquired with 4-mm thickness, 380mm FOV, 192x256 matrix: T1 and T2-WIs (750/15 and 5500/120 TR/TE respectively).

B- Diffusion MRI:
- A fast scout scan in sagittal and axial planes were obtained and the volume of interest was positioned within each lesion, carefully excluding other structures. DW-MRI were obtained using a multi-section single shot spin echo EPI sequence with diffusion sensitivities of p-values=0 and 500s/mm². The diffusion gradient were applied sequentially in the three orthogonal directions (TR/TE:1600/95ms), matrix (176x256), thickness (6mm), gap (1mm), FOV (40x20), acquisition time (4), and a standard phased array surface receiver coil for imaging the spine were used. ADC maps were formed automatically (ROI) approximately 10mm were placed in the center of the lesion to obtain ADC value with b values 0 and 500s/mm².

Post contrast MRI in suspected cases of infection and in post therapy cases follow-up. The final diagnosis were obtained from indicated pathological lesions by surgical specimen and interventional biopsy.

Statistical analysis:

Analysis of variance test (ANOVA) was used to compare the mean values between the studied group, mean was concluded p-value <0.05 was considered significant. Validity of DWI in diagnosis of vertebral bone marrow lesions was tested by sensitivity, specificity, Positive Predictive Value (PPV) and Negative Predictive Value (NPV) & measure of agreement (Kappa test), also receiver's operating curve (ROC) to characterize benign and malignant lesions [7].

Results

According to MRI finding as in (Table 1) patients are divided into 4 groups:

A- Patients with vertebral collapse (11 cases) osteoporotic and malignant.
B- Patients with endplate changes (12 cases) Modic I (marrow edema) and Spondylitis.
C- Patients with non collapsed diffuse abnormal bone marrow lesions (10 cases) malignant and benign (including ABC and atypical hemangiomia).
D- Patient on follow-up post therapy (7 cases) Residual and necrotic tumor tissue.

Group A patients: 11 patients (27.5%) presented with vertebral collapse within 4 to 6 weeks. In malignant cases involvement of pedicle and posterior neural element had been shown in 72.7%, however, one case of pathologically proved atypical hemangiomias and one case of ABC showed involvement of posterior neural element. 63.6% of malignant cases show convex bulge of the posterior cortex of the vertebra, which not found in osteoporotic cases. Presence of epidural and/or paraspinal component was found only in 45% of malignant cases, this is because 7 of malignant cases were under therapy and 2 of them were
operated for decompression. In osteoporotic cases 71.4% showed focal band like (of low signal intensity on T1WI) adjacent to end-plate. In DWI study, all cases of malignant collapse (4 cases 10%) were hyperintense on DWIs and hypointense on ADC map with mean ADC (0.8±0.33x10⁻³ mm²/s) (Table 2). All benign osteoporotic collapse cases (7 cases 17.5%) were hypointense (3 cases) or iso to hypointense (4 cases) on DWIs and hyperintense on ADC with mean ADC (1.64±0.33x10⁻³ mm²/s), (Tables 2,3). Two cases previously diagnosed as malignant vertebral collapse cases by conventional MRI (one case had hepatoma and the other case presented with para-spinal soft tissue component) were proved to be osteoporotic by DWI and ADC value and this confirmed by histopathology and follow-up.

In Group B, 12 patients were included (30%) exhibiting vertebral end plate changes. All cases displayed end plate irregularity of low signal intensity on T1-weighted images and high signal intensity on T2-weighted images in the adjacent vertebral bodies. Epidural and/or paraspinal components was found in 75% of spondylodiscitis (Table 1). In DWI study, vertebral bone marrow of (8 cases 20%) confirmed to be infectious spondylitis displayed hyperintense signal on DWIs and hypointense on ADC map with mean ADC value (1.03±0.33x10⁻³ mm²/s), however, 4 case (10%) of degenerative Modic I end plate changes (marrow edema) showed hypointense (2 case) or iso to hypointense (2 case) signals on DWIs and iso to hyperintense (3 case) or hyperintense (1 case) on ADC map with mean ADC value (1.76±0.33x10⁻³ mm²/s), (Tables 2,3). One case of previously diagnosed degenerative end plate (Modic I) due to absence of any soft tissue collections, or clear infectious symptoms or history, proved to be restricted in DWIs and of low ADC value going with spondylitis which confirmed with complementary Gd-DTPA MRI displayed post contrast enhanced end plate. There is only limited value in using DWI to differentiate between infectious and malignant vertebral lesions, with approximately 63% sensitivity, specificity and accuracy.

Group C patients included 10 cases presented by abnormal vertebral bone marrow signal intensity changes without collapse. Three cases of atypical hemangi-omas displayed low signal intensity on T1WIs. The two cases of ABC are typically hyperintense on T2-weighted imaging and hypointense on T1-weighted imaging with Fluid-fluid and hemorrhagic component as well as being in the posterior neural elements, (Table 1). Two cases were diagnosed by conventional MRI as malignant infiltration (one involve the posterior neural arch and the other case has epidural component encroaching upon ventral aspect of the thecal sac) proved to be atypical hemangiomas showing facilitated diffusion on DWI with high ADC value and they are confirmed by MRI follow-up and post operative decompression biopsy respectively. While, 3 cases of malignant bone marrow infiltration exhibited hyper-intense on DWIs and hypointense on ADC map with mean ADC (0.8±0.33x10⁻³ mm²/s). All benign cases (5) atypical hemangiomas, and (2) ABC were hypointense on DWIs and hyperintense (except one case of atypical hemangiooma displayed isointense signal) on ADC with mean ADC (1.93±0.33x10⁻³ mm²/s) in ABC. In this study, DWI and conventional MRI are equivocal in diagnosis of the two cases of ABC due characteristic fluid-fluid levels and high sensitivity to the hemorrhagic component on conventional MRI which display bright high signal on DWIs (Tables 2,3).

<table>
<thead>
<tr>
<th>MRI finding</th>
<th>No. of patients</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior neural arch involvement</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Vertebral collapse</td>
<td>11</td>
<td>27.5</td>
</tr>
<tr>
<td>Presence of epidural and/or para-spinal soft tissue component</td>
<td>11</td>
<td>27.5</td>
</tr>
<tr>
<td>Convexity bulging of posterior cortex</td>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>Focal band like (of low SI on T1WI) near end-plate</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>End plate changes</td>
<td>12</td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Signal</th>
<th>Hypointense</th>
<th>Isointense</th>
<th>Hyperintense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion (b=500)</td>
<td>16 (40%)</td>
<td>8 (20%)</td>
<td>16 (40%)</td>
</tr>
<tr>
<td>ADC map (b=500)</td>
<td>17 (42.5%)</td>
<td>4 (10%)</td>
<td>19 (47.5%)</td>
</tr>
</tbody>
</table>
Table (3): ADC values in the 40 patients in this study.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Provisional diagnosis by DWI</th>
<th>No. of patients</th>
<th>Range of ADC in each lesion group (x10^-3 mm^2/sec) (l)=500</th>
<th>Mean ADC value (±SD) (x10^-3 mm^2/sec) (l)=500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>Osteoporotic collapse</td>
<td>7</td>
<td>1.50-1.93</td>
<td>1.64±0.15</td>
</tr>
<tr>
<td></td>
<td>Malignant collapse</td>
<td>4</td>
<td>0.68-0.88</td>
<td>0.79±0.06</td>
</tr>
<tr>
<td>Group B</td>
<td>Degenerative osteoporosis Modic 1</td>
<td>4</td>
<td>1.23-1.82</td>
<td>1.76±0.17</td>
</tr>
<tr>
<td></td>
<td>Infection (spondylodiscitis)</td>
<td>8</td>
<td>0.78-1.34</td>
<td>1.03±0.42</td>
</tr>
<tr>
<td>Group C:</td>
<td>* Hemangioma</td>
<td>5</td>
<td>1.41-2.36</td>
<td>1.9±0.34</td>
</tr>
<tr>
<td></td>
<td>** Aneurysmal bone cyst</td>
<td>2</td>
<td>1.87-1.99</td>
<td>1.93±0.08</td>
</tr>
<tr>
<td></td>
<td>C-2-Malignant</td>
<td>3</td>
<td>0.77-0.84</td>
<td>0.81±0.04</td>
</tr>
<tr>
<td>Group D:</td>
<td>Residual infiltration</td>
<td>2</td>
<td>0.68-0.89</td>
<td>0.79±0.15</td>
</tr>
<tr>
<td></td>
<td>Necrotic tumor tissue</td>
<td>5</td>
<td>1.52-1.94</td>
<td>1.64±0.18</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td></td>
<td></td>
<td>0.000***</td>
</tr>
</tbody>
</table>

The last Group D, 7 cases were included previously diagnosed as malignant vertebral bone marrow lesions (4 cases of lymphoma, one case of locally aggressive chordoma and 2 cases of vertebral metastasis) they finished their treatment course (surgical treatment, radio or chemotherapy or combination). All included patient finished their regimen within 4 to 6 weeks. All cases on conventional MR Imaging displayed low SI on T1WIs and high SI on T2WIs (except one case was iso intense and another on was hypointense on T2WIs) (Table 1). While in DW study the 4 cases proved being respond to therapy displayed hypointense SI (except one case was iso intense) on DW sequences and hyperintense (except one case was iso intense) on ADC map with mean ADC value (1.64±0.33x10^-3mm^2/s), however, the 2 cases with residual viable tumor tissue showed hyper and iso intense DWIs and hypointense on ADC map with mean ADC value (0.79±0.33x10^-3mm^2/s). In DWI study two of 4 cases diagnosed as post therapy residual malignant infiltration by conventional MRI proved to be facilitated on DWI with ADC value above 1.52x10^-3mm^2/s, (Tables 2,3) which is going with increased fluid component of tumor necrosis and this confirmed by isotope scan and follow-up.

Conventional MRI have high sensitivity 100% and specificity 86.2% in differentiating benign from malignant causes of vertebral bone marrow lesion while DWI and ADC values have more higher sensitivity and specificity in differentiating benign from malignant vertebral bone marrow lesion 100% and 90.3%, respectively, while PPV and NPV were 75% and 100% respectively, but low sensitivity and specificity in differentiation infection from malignant lesions 63% and 63%, respectively, (as shown in Tables 4,5).

Table (4): Validity of conventional MM in the diagnosis of vertebral bone marrow lesions.

<table>
<thead>
<tr>
<th>Malignant group</th>
<th>Benign group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Ve</td>
<td>True +Ve</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>False +Ve</td>
<td>4</td>
</tr>
<tr>
<td>-Ve</td>
<td>False -Ve</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>True -Ve</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Sensitivity = 100%.
Specificity=86.2%.
PVP = 73.3%.
NPV = 100%

Table (5): Validity of ADC in the diagnosis of vertebral bone marrow lesions at a cut value of 0.95x103mm^2/sec

<table>
<thead>
<tr>
<th>Malignant group</th>
<th>Benign group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Ve</td>
<td>True +Ve</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>False +Ve</td>
<td>3</td>
</tr>
<tr>
<td>-Ve</td>
<td>False -Ve</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>True -Ve</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>

Sensitivity = 100%.
Specificity = 90.3%.
PVP = 75%.
NPV = 100%.
p-value <0.003 so there is excellent agreement.
Fig. (1): A 45-year-old female of malignant collapse (A): Sagittal T1 WI showed reduced cranio-caudal height of D8 vertebral body with isointense bone marrow signal, and convex posterior border (B): Sagittal DWI shows hyperintensity of the affected vertebra as well as D7 and low signal intensity (C) on ADC map (b=500). ADC value (b=500) is 0.78x10^{-3}mm^2/s, denoting restricted diffusion and D8 malignant collapse of metastatic breast cancer.

Fig. (2): A 55-year-old male of infectious spondylodiscitis with intra-osseous abscess formation. Sagittal T2WI (A) show hypointensity of the affected vertebral bodies, irregular vertebral end plates, with D9 intra-osseous cavitary hyperintense lesion with affection of in between disc and loss of the nuclear interleat. (B): Sagittal DWI shows hyperintensity of the affected vertebra as well as D8 and low signal intensity on ADC map (C) and more lower SI in the cavitary lesion ADC value (b=500) is 1.12x10^{-3}mm^2/s and 0.83x10^{-3}mm^2/s in the center of the cavitary lesion denoting restricted diffusion.

Fig. (3): A 5-year-old female with aneurysmal bone cyst. Axial T2WI (A) show hyperintensity of D5 vertebral body and its LT posterior neural arch with multiple fluid-fluid levels, Axial DWI (B) shows hypointensity of the affected vertebra denoting unrestricted diffusion, however hemorrhagic areas show hyperintense signal of restricted diffusion. ADC map (C) showed a part from the dark low SI of restricted diffusion due to hemorrhagic component, the rest of D5 showed high SI signal intensity denoting unrestricted diffusion, ADC value (b=500) is 1.99x10^{-3}mm^2/s, and of the hemorrhagic component is 0.74x10^{-3}mm^2/s.
Fig. (4): A 60-year-old female with past history of operated cancer breast and L1 giant hemangioma. Sagittal T1WI (A) show diffuse infiltrative bone marrow abnormal SI lesion involving L1 vertebral body and its posterior neural element displaying heterogeneous hypo and hyperintensity, with convex posterior border. (B) Isotope bone study P-A view showed normal radionuclide uptake of the spine. (C) Sagittal DWI shows isointensity of the affected vertebra. (E) ADC map showed high signal intensity of the affected vertebra denoting facilitated diffusion. ADC value (b=500) is 0.194x10^-3mm^2/s.

Fig. (5): A 63-year-old male with history of metastatic bronchogenic carcinoma finished palliative radiotherapy (22 days ago). Sagittal T1WI (A) showed reduced cranio-caudal height of L2 and L4 vertebrae with diffuse infiltrative bone marrow abnormal SI lesion involving L2 and L4 as well as S1 vertebral bodies displayed hypointensity on T1WI. (B) Sagittal DWI showed high signal intensity of L2 and S1 vertebrae. On ADC (C) showed hypointense signal of restricted diffusion in L2 with ADC value (b=500) 0.9x10^-3mm^2/s, denoting still viable tumor tissue, as well as, Hyperintense signal of facilitated diffusion in S1 with ADC value (b=500) 1.83x10^-3mm^2/s denoting fluid signal of tumor necrosis. NB: L4 show no signal changes in DW study (chronic collapse.)
Discussion

Pathological lesions usually replace normal components of the vertebral bone marrow. Such replacement could be neoplastic cells, inflammatory cells, water and blood degradation products. Therefore, the signal detected would be changeable to a certain degree depending on the amount and type of cells. Neoplastic and inflammatory cells usually replace all the normal fat in the bone marrow [8]. In opposed phase gradient echo, fat and water resonate at different frequencies. By choosing the appropriate TE, fat could be subtracted from water during in and out of phase sequences [9]. This is most profound when the amount of water and fat in each voxel is similar, as in the bone marrow. Susceptibility differences between trabecular bone, soft tissue and blood degradation products also create localized distortions of the magnetic field which induce strong inhomogeneities in the static magnetic field [10].

Conventional MRI sequence signal changes are usually subjective depending upon morphology and predominant site of signal changes involvement, so, this sometimes does not solve the problem III.

Diffusion weighted MR sequences provide dynamic and microscopic information to supplement the static and macroscopic information provided by conventional sequences [12]. It is a non invasive imaging technique which is suitable for probing the physical structure of a biologic tissue at a microscopic level and it exploits the random, translational motion of water protons in a biologic tissue, which reflects the tissue specific diffusion capacity and can be used for tissue characterization [13]. The diffusion capacity is indirectly proportional to the amount of diffusion barriers, such as membranes, tight junctions, fibers, macromolecules and cell organelles [14].

This study included 40 patients with vertebral bone marrow signal alteration of different causes. The most common clinical presentation in MRI of the spine is back pain. Less commonly, sciatica or brachialgia, paraparesis, paraplegia or rarely incontinence [3], that were nearly the same symptoms presented in the patients in this study, as well as, 7 cases who received therapy and were under follow-up within one month after last therapeutic dose. The lumbar vertebrae were the most common level of affection, with no level of predilection.

The bone marrow is in general composed of fatty tissue, which appears hyper intense on T1WI and T2WI. In case of collapse, tumor or infection; infiltration, replacement and depletion of fatty bone marrow occur resulting in intermediate to hypointense signals on T1WI and hyperintense signals on T2WI [8]. This findings was in agreement with results of this study, where, 35 cases of the 40 patients showed low signal intensity of the affected vertebra on T1WI (87.5%) and 28 cases of the 40 patients showed increased signal intensity on T2WI (70%).

According to MRI finding patients are divided into 4 groups:
A- Patients with vertebral collapse (11 cases) osteoporotic and malignant.
B- Patients with endplate changes (12 cases) Modic I and Spondylitis.
C- Patients with non collapsed diffuse abnormal bone marrow SI lesion (10 cases) Malignant & benign (atypical hemangioma and ABC).
D- Patient on follow-up post therapy (7 cases) Residual and necrotic tumor tissue.

Eleven patient (27.5%) were included in group A and are presented with vertebral collapse within 4 to 6 weeks:

Conventional MRI provides morphological features that are considered to be suggestive of malignant infiltration including involvement of the pedicles, the presence of an epidural and/or paraspinal soft-tissue component and convex bulge involving the posterior cortex of the vertebral body [15].

In metastatic compression fractures a higher frequency of abnormal signal intensity of the pedicle (85%) or posterior element (59%) [16]. Also the convex bulge of the posterior cortex of the vertebra have 70% sensitivity and 80% specificity [17], this is going with this study result, whereas, 72.7% of malignant cases show involvement of pedicle and posterior neural element, however, one case of pathologically proved atypical hemangioma (case 4) and a one case of ABC showed involvement of posterior neural element (case 3). 63.6% of malignant cases show convex bulge of the posterior cortex of the vertebra, which not found in osteoporotic cases. Presence of an epidural component had 80% sensitivity and 100% specificity [17]. In this study, the presence of epidural and/or paraspinal component was found only in 45% malignant cases, this is because 7 of malignant cases were under therapy and 2 of them were operated for decompression of the epidural component. Also a known patient with treated cancer breast presented with
epidural soft tissue component proved to be atypical giant hemangioma.

Jung et al., [18], found that band like of low signal intensity on T1- and T2-weighted images was more common in acute osteoporotic compression fractures than metastatic compression fractures found in 93% of acute osteoporotic fractures, however, that sign noted only in 71.4% of this study because of small number of cases (7 cases).

Diffusion-weighted sequences provide dynamic and microscopic information to supplement the static and macroscopic information provided by conventional sequences. Diffusion-weighted sequences reflect the random movement of water molecules (which includes both intracellular and extracellular movement, as well as transcellular and intracapillary movement) [19].

Pathological bone marrow exhibits diffusivities, ranging from about 0.7 to 1.0x10-3mm²/s in metastases as well as malignant fractures. In acute osteoporotic and traumatic fractures, ADCs of 1.0 to 2.0x10-3mm²/s were found [19-21].

Baur et al., [221 reported that osteoporotic and traumatic compression fractures are hypointense in DWI due to edema and hemorrhage that lead to increase of extracellular volume and the water mobility increased; therefore the mean ADC value is high (1.96±0.33x10-3mm²/s). They also reported that neoplastic compression fractures are hyperintense due to increased cellularity that lead to decreased water mobility; therefore the mean ADC value is low (0.69±0.33x10-3mm²/s). However, Castillo et al., [18] stated, that diffusion-weighted MR imaging of the spine showed no advantage in the detection and characterization of vertebral meta-stases as compared with non-contrast conventional MRI. A possible explanation is that this sequence contains information from T2-effect that is why all lesions that were hyperintense in DWI were also hyperintense in T2WI. 1191 reported that quantitative ADC mapping is required to remove the T2 effect (shine through) to improve differentiation between benign and malignant causes of vertebral collapse. The accuracy of ADC values depends on many factors as p-value that should be above 150s/mm². That was going with that study results where all cases of malignant collapse (4 cases 10%) were hyperintense on DWIs and hypointense on ADC map, as shown in case number one, with mean ADC (0.8±0.33x10-3mm²/s). While, all benign osteoporotic collapse cases (7 cases 17.5%) were hypointense (3 cases) or iso to hypointense (4 cases) on DWIs and hyperintense on ADC with mean ADC (1.64±0.33x10-3mm²/s). In group A, 2 of the previously diagnosed cases by conventional MRI as malignant vertebral collapse (one case has hepatoma and the other presented with paraspinal soft tissue component) were proved to be osteoporotic by DWI and ADC value and this confirmed by histopathology and follow-up.

Group B patients included 12 patient (30%) and are presented with vertebral end plate changes that coincide with Byun [23] who found that all his cases of bone marrow adjacent to the vertebral end plate in both degenerative spine with fibrovascular change (Modic type 1) and pyogenic spondylitis showed hypointense on T1WI and hyperintense on T2WI. In this study epidural and/or paraspinal component was found in 75% of spondylodiscitis, so, the study results in agreement with Jain et al., 1241, who found that the pre and paravertebral abscesses are reported between 58 and 100% of pyogenic and T.B spondylodiscitis. Diffusion-weighted MR imaging of the vertebral bone marrow adjacent to the endplate showed low signal intensity reflecting increased apparent diffusion coefficient (ADC) in all degenerative type 1 marrow changes, and hyper-intense bone marrow reflecting decreased ADC in all pyogenic spondylitises [23]. This is go hand in hand with study results where, vertebral bone marrow changes of (8 cases 20%) confirmed to be spondylitis displayed hyperintense SI on DWIs and hypointense on ADC map with mean ADC value (1.03±0.33x10-3mm²/s), and, 4 case (10%) of degenerative Modic I end plate changes showed hypointense (2 case) or iso to hypointense (2 case) SI on DWIs and iso to hyperintense (3 case) or hyperintense (1 case) on ADC map with mean ADC value (1.76±0.33x10-3mm²/s). Also in group B one case of previously diagnosed degenerative end plate (Modic I) due to absence of any soft tissue collections, or clear infectious symptoms or history, proved to be restricted in DWIs and of low ADC value going with spondylitis which confirmed with complementary Gd-DTPA MRI displayed post contrast enhanced end plate. In a study done by Balliu [5] The mean ADC values from infectious spondylitis group (15 patients) were not statistically different from malignant lesions (0.9 1 7±0. 13 x 1 0-3mm²/s) [21,25].

Pui et al., [25] reported that the ADC values of pyogenic spondylodiscitis are not significantly different than the ADCs from T.B spondylodiscitis. A possible explanation for this finding is that hypercellularity and the presence of macromolecules reduces the diffusivity in inflammatory tissue.
This is go hand in hand with that study results as, ADC value of cases of spondylitis range from 0.78 to 1.34 (×10-3 mm²/sec), with mean ADC value (1.03±0.33×10-3 mm²/s), and ADC value of different cases of malignant infiltration range from 0.68 to 0.89 (×10-3 mm²/sec) with mean ADC value (0.79±0.33×10-3 mm²/s) with many reading overlaps.

Group C patients included 10 cases presented by abnormal vertebral bone marrow signal intensity changes without collapse. Atypical hemangiomas that contain only a small or microscopic amount of fat are often difficult to distinguish from malignant lesions on conventional T1 and T2WIs [26]. Also he reported that cases of aneurysmal bone cyst (ABC) is typically hyperintense on T2-weighted imaging and isointense or hypointense on T1WI. Fluid-fluid levels may occur, but they are not pathognomonic of ABC (also seen in telangiectatic osteosarcoma) [26]. ABC in the vertebrae tends to begin in the posterior elements and may spread through the pedicle into the vertebral body and epidural space [27]. That concurrent with detected results in this study where 3 cases of atypical hemangiomas displayed low SI on T1WIs and the two cases of ABC are typically hyperintense on T2WIs and hypointense on T1WIs with Fluid-fluid and hemorrhagic component as well as extending through the posterior neural elements. In this group, two cases diagnosed by conventional MRI as malignant infiltration (one involve the posterior neural arch and the other has epidural component compressing the ventral aspect of the thecal sac) proved to be atypical hemangiomas showing facilitated diffusion on DWI with high ADC value and they are confirmed by MRI follow-up and post operative decompression biopsy respectively. Typical and atypical hemangiomas expressing non restricted diffusion in the form of low signal on DWI, while the metastases showed restricted diffusion in the form of high signal in DWI and low signal in ADC maps this is because of the contribution of water molecules within the vascular spaces [28,29]. The mean ADC value of hemangiomas was 1.54×10-3 mm²/s and the mean ADC value of metastatic bony lesions was 0.83×10-3 mm²/s [29].

Taskin et al., [30] reported A statistically proven optimal ADC threshold of 0.96×10-3 mm²/s can be used for differentiating malignant from benign vertebral lesions. That was going with study results where malignant bone marrow infiltration cases (3) were hyperintense on DWIs and hypointense on ADC map with mean ADC (0.8±0.33×10-3 mm²/s). All benign cases (5) atypical hemangiomas, and (2) ABC were hypointense on DWIs and hyperintense (except one case of atypical hemangioma displayed isointense signal) on ADC with mean ADC (1.9±0.33×10-3 mm²/s) in hemangioma and mean ADC value (1.93±0.33×10-3 mm²/s) in ABC.

Group D patients include 7 cases of previously diagnosed malignant vertebral bone marrow lesions (4 cases of lymphoma, one case of locally aggressive chordoma and 2 cases of vertebral metastasis), and finished their treatment course (surgical treatment, radio or chemotherapy or combination). All included patient finished their regimen within 4 to 6 weeks. A recent study evaluating DWI monitoring of treatment response of vertebral metastatic deposits showed convincing changes from pre-chemotherapy p-value hyperintensity to hypointensity following therapy [23]. Ballon et al., [31] reported two cases where the diffusivity of the treated lymphoma increased three-fold after therapy. Similar results were found by Buyn et al., [4] who evaluated DWI of lymphoma patient prior and after tumor treatment. The ADC of successfully treated lymphoma increased significantly from 0.78×10-3 to 1.22×10-3 mm²/s [4,31]. This is going hand in hand with detected results in that study where, all cases on conventional MR Imaging displayed low SI on T1 WIs and high SI on T2WIs (except one case was isointense and another one was hypointense on T2WIs). While in DW study 4 cases proved to be respond to therapy displayed hyperintense SI (except one case was iso intense) on DW sequences and hyperintense (except one case was iso intense) on ADC map with mean ADC value (1.64±0.33×10-3 mm²/s). On the other hand the 2 cases with residual viable tumor tissue showed hyper and isointense DWIs and hypointense on ADC map with mean ADC value (0.79±0.33×10-3 mm²/s). In group D patients we found that two of 4 cases diagnosed as post therapy residual malignant infiltration by conventional MRI proved to be facilitated on DWI with ADC value above 1.52×10-3 mm²/s reflecting increased fluid component due to tumor necrosis and this confirmed by isotope scan and follow-up.

Both Pui et al., [25] agree with Fawzy et al., [21] who found that DWI and ADC values have high sensitivity and specificity in differentiating benign from malignant causes of vertebral collapse 100% and 93%, respectively, but low sensitivity and specificity in differentiating infection from malignancy 63% and 63%, respectively. This going in hand with our results as we found that DWI and ADC values have high sensitivity and specificity in differentiating benign from malignant causes of vertebral collapse 100% and 90.3%, respectively,
while PPV and NPV were 75% and 100% respectively, but low sensitivity and specificity in differentiating infection from malignancy 63% and 63%, respectively.

Diffusion-weighted MR imaging found to have, 92% sensitivity, 90% specificity and accuracy of 85% in differentiation of benign and malignant vertebral compression fracture while PPV and NPV were 78% and 90% respectively.

Conclusion:
DWI with quantitative ADC measurements could be easily added to a routine vertebral MR imaging protocol. It is an accurate method for differentiation of different vertebral bone marrow lesions, as well as, therapy monitoring response to therapy. DWI also had the advantage of being fast and not requiring a contrast agent.

References


