Role of T1 Weighted and Diffusion Weighted Magnetic Resonance imaging application in the diagnosis of osteoporosis in lumbar spine in postmenopausal women

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ABSTRACT:

Background: Postmenopausal Osteoporosis is one of the most common causes of primary osteoporosis. For two decades, diffusion-weighted imaging (DWI) has been applied to the evaluation of intracranial diseases, but technical advancement make it possible to apply DWI measurements to extra cranial sites, including vertebral column.

Objective: Using diffusion-weighted MR imaging technology to determine the DWI and ADC values of lumbar vertebral body in postmenopausal women in correlation with the DEXA t-scores.

Patients and Methods: A cross sectional analytical study was conducted at Al-Yarmouk Teaching hospital in Baghdad city. A total of 80 postmenopausal women, was recruited from subjects who underwent DEXA of the spine and categorized into three groups according to their t-score: Normal BMD, Osteopenia, and Osteoporosis. Then MRI study done for all of them including: T1, T2, DWI, and ADC value measurement.

Results: The values of ADC at L3 vertebra were (0.46 ± 0.098) × 10^{-3} \text{mm}^2/\text{s}, (0.42 ± 0.084) × 10^{-3} \text{mm}^2/\text{s}, and (0.39 ± 0.052) × 10^{-3} \text{mm}^2/\text{s} for the three groups: the normal, osteopenic, osteoporotic respectively. The values of the diffusion signal intensity values at L3 vertebra were 134.5 ± 5.7 \text{mm}^2/\text{s}, 112.7 ± 3.4 \text{mm}^2/\text{s}, 101.3 ± 4.4 \text{mm}^2/\text{s} respectively. There was a significant difference among the three groups in both diffusion and ADC measurement.
Conclusion: Both diffusion and ADC values are significantly lower in subjects with postmenopausal osteoporosis. There is a significant positive relationship between T score that was determined by DEXA, and the ADC value.

Keywords: diffusion weighted magnetic resonance imaging, T1, osteoporosis.

INTRODUCTION

Osteoporosis is currently defined by the World Health Organization (WHO) as "a systemic skeletal disease with a low bone mass, micro architectural deterioration of the bone tissue, and a consequent increase in bone fragility with susceptibility to fracture, which usually involves the spine, wrist, ribs, hip, hummers, or pelvis". (1, 2)

The bone mass accounts for about 70% of the variance in the bone strength and is the only variable that can be accurately determined, its measurement as bone mineral density (BMD) or bone mineral content (BMC) currently are used in the practical basis for the diagnosis of osteoporosis. (3, 4, 5)

Menopause is a natural physiological phenomenon resulting from primary ovarian failure secondary to apoptosis or programmed cell death.

At menopause the normal bone turnover cycle is impaired by estrogen deficiency. The osteoclastic resorption activity increases while the osteoblastic activity decreases. As a result, the amount of bone resorbed exceeds the amount deposited, which leads to a net loss of bone. (6)

For the time being, the standard diagnosis of osteoporosis was dependent on the measurement of the mineralized component of the bone. This bone mineral density (BMD) is assessed with the dual-energy X-ray absorptiometry (DEXA), which is considered the gold standard. (7, 8)

Although DXA examination is economical and noninvasive, it is known to have reduced sensitivity. (9)

MR imaging studies until nowadays have concentrated on the study of trabecular bone architecture or microscopic magnetic field distribution in bone to assess fracture risk. Although MR imaging techniques employ no radiation compared to DXA and QCT, one feature is common to all these techniques which is the focus on measuring the structural end-point of bone loss. But they provide no information on the physiological or functional changes associated with osteoporosis. (10, 11)
The limitations in using DXA:

- DXA measurements are two-dimensional.
- DXA cannot differentiate between cortical and trabecular bone.
- Reference data for BMD supplied by overseas manufacturers are often not appropriate for our local populations.
- Degenerative disorders, vascular calcifications like aorta or other arteries, previous contrast media, and fractures or deformities may falsely elevate BMD and even invalidate interpretation of spine scans, particularly in the elderly.
- Pitfalls related to operator may occur. \(^{(12)}\)

Diffusion-Weighted imaging (DWI):

Until two decades ago, diffusion-weighted imaging (DWI) has been applied to evaluate intracranial diseases, such as stroke, trauma, epilepsy, depression, neurotoxicity, and dementia. \(^{(13, 14)}\) The developments of multichannel coils, echo-planar imaging (EPI), parallel imaging, and high gradient amplitudes have been used in expanding the use of DWI. DWI measurements are not taking a lot of time to perform (typically 1–5 minutes) and do not require the administration of exogenous contrast medium. In addition to that, both qualitative and quantitative information can be obtained from DWI examination and so that it can assist in pathology assessment. \(^{(15)}\)

On MR scanners, the diffusion sensitivity is easily changed by changing the parameter known as the “b value,” Water molecules which have higher degree of motion or have greater diffusion distance (like those within the intravascular space) will show signal attenuation with small b values (e.g., \(b = 50–100\) s/mm\(^2\)). While water molecules that have slower degree of motion or have smaller diffusion distances will show more signal attenuation with large b values (e.g., \(b = 1,000\) s/mm\(^2\)), because these show more gradual signal attenuation with increasing b values. \(^{(16)}\)

ADC is measured by obtaining the MR signal at least two times. So an ADC map can be established in this way by combining two images, one with diffusion weighting and another without that or using two b-values in a way that the lower b-value is not large enough to remove the effects of perfusion, containing information about perfusion as well as diffusion components. \(^{(17)}\) Figure (1.1). Signal loss in DWI is proportional to the component of molecular displacement in the same direction as that of the diffusion gradient. \(^{(18)}\)
AIMS OF STUDY

1. Using (DWI) to quantitatively determine the diffusion signal intensity and apparent diffusion coefficient (ADC) values of lumbar vertebral body in postmenopausal women.
2. Study the difference of those values in the different groups of bone density and analyze the correlation with the DEXA t-scores.
3. Study the correlation between T1 values and DEXA t-score.

PATIENTS AND METHODS

A cross sectional analytical study had been conducted in Al-Yarmouk teaching hospital in Baghdad city, performed from February 2016 to October 2016. A total of 80 postmenopausal women, mean age were (63.2 ± 7.2 years) (range 55 – 79 years) was recruited randomly from subjects who underwent DEXA (StratosdR, DMS) of the spine.
The exclusion criteria were:
- Patient with a known pre-existing bone disease such as tumor, metastasis, or metabolic disorder
- History of traumatic spinal injury.
- The patient on drug therapy that may affect BMD were not included to the study
- Radiological evidence of spondylodiscites confirmed by radiological features.
- History of previous operation or radiotherapy.

The bone density of the vertebral body was expressed as a T-value measured by a postero-anterior projection DXA at L3 lumbar vertebra. According to their T scores results and World Health Organization criteria, the patients were categorized into three groups:
1. Normal BMD (T>−1)
2. Osteopenia (T = -1 to −2.5)
3. Osteoporosis (T<−2.5)

MRI was performed using a 1.5T MRI scanner (Philips, Achieva) using a spinal array surface coil. Sagittal T1 and T2 weighted imaging of the lumbar spine were acquired by using a fast spin-echo sequence. The DWI done for all patients using single-shot spin-echo planar imaging sagittal diffusion-weighted sequence at bvalues of 0 and 400 mm²/s. Regions of interest (ROI) as circle of size 1 cm² were placed in the center of L3 vertebra (0.5 cm away from the periphery of vertebra to avoid the cortex). For quantitative measurement of the T1, DWI, and ADC values of the L3 vertebra, three such ROIs were placed and the mean value of these three values was calculated to decrease the chance of error. The ADC values were expressed as mean ± standard deviation in the form of (value) x10⁻³ mm²/s, while T1 and DWI value were expressed as SNR.

RESULTS

According to the total T score of lumbar measured by DXA, the patients were divided into: Normal, osteopenic & osteoporotic.

Figure (3.1): shows percentage of each study group
According to age, patients were divided into three groups: table (3.1)

- 55-64 years, 38 women (47.5%). According to their t-score: 18 were normal, 12 were osteopenic, and 8 were osteoporotic.
- 65-74 years, 33 women (41.25%). According to their T score: 10 were normal, 13 were osteopenic, and 10 were osteoporotic.
- ≥ 75 years, 9 women (11.25%). According to their T score: 5 were osteoporotic and 4 were osteopenic.

There was a significant association between age of the patient and the BMD represented by t-score, in a way that increasing the age of patient associated with a lower BMD. P value (0.002).

Table (3.1): shows number of patients of each age group correlated with their t-score.

<table>
<thead>
<tr>
<th>Age versus t-score</th>
<th>55-64 years</th>
<th>65-74 years</th>
<th>≥ 75 years</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>18 (47.4%)</td>
<td>10 (30.3%)</td>
<td>0 (0%)</td>
<td>28 (35%)</td>
</tr>
<tr>
<td>Osteopenic</td>
<td>12 (31.6%)</td>
<td>13 (39.4%)</td>
<td>4 (44.4%)</td>
<td>29 (36%)</td>
</tr>
<tr>
<td>Osteoporotic</td>
<td>8 (21%)</td>
<td>10 (30.3%)</td>
<td>5 (55.6%)</td>
<td>23 (29%)</td>
</tr>
<tr>
<td>Total</td>
<td>38 (47.5%)</td>
<td>33 (41.25%)</td>
<td>9 (11.25%)</td>
<td>80 (100%)</td>
</tr>
<tr>
<td>P value</td>
<td>0.06</td>
<td>0.034</td>
<td>0.012</td>
<td>0.002</td>
</tr>
</tbody>
</table>

There was a significant association age of the patient and the ADC values, in a way that increasing the age of patient associated with a lower ADC value. P value (0.005). Table (3.2)
Table (3.2): shows mean ADC value of L3 vertebra of each age group.

<table>
<thead>
<tr>
<th>Age</th>
<th>55-64 years</th>
<th>65-74 years</th>
<th>≥ 75 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ADC value (mm^2/s)</td>
<td>0.44 ± 0.01</td>
<td>0.41 ± 0.006</td>
<td>0.37 ± 0.008</td>
</tr>
<tr>
<td>P value</td>
<td>0.01</td>
<td>0.04</td>
<td>0.005</td>
</tr>
</tbody>
</table>

The differences between groups with different bone density:

According to the total t-score of lumbar, the patients were divided into normal, osteopenic and osteoporotic groups. The values of the diffusion signal intensity at L3 vertebra represented as an (SNR value) were 134.5 ± 5.7, 112.7 ± 3.4, 101.3 ± 4.4 respectively (figure 3.3) (table 3.3). By comparing the values of the three groups, there was a significant difference among the three groups (P= 0.023).

By comparing the values between two groups, there was significant difference between the normal group and osteoporotic group (P = 0.009), the values between normal group and osteopenic group showed significant difference (P = 0.03), while the values between osteopenic group and osteoporotic group showed no significant difference (P = 0.307);

![Diffusion](image)

**Figure (3.3):** Graph shows diffusion values for normal, osteopenic, and osteoporotic groups.

The values of ADC at L3 vertebra were (0.46 ± 0.01) × 10^{-3} mm^2/s, (0.42 ± 0.008) × 10^{-3} mm^2/s, and (0.39 ± 0.006) × 10^{-3} mm^2/s for the three groups: the normal, osteopenic, osteoporotic respectively (figure 3.4) (table 3.3). There was significant difference among the three groups (P = 0.003).
Comparing the values between two groups, there was significant difference between the normal group and osteopenic group (P= 0.009), the values between normal group and osteoporotic group also showed significant difference (P = 0.002) and also significant between osteopenic group and osteoporotic group (P= 0.005).

![ADC Graph](image)

**Figure (3.4):** Graph shows ADC values for normal, osteopenic, and osteoporotic groups.

**Table (3.3):** Data of DWI and ADC values in three bone density groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal group</th>
<th>Osteopenic group</th>
<th>Osteoporotic group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion (SNR)</td>
<td>134.5 ± 5.7</td>
<td>112.7 ± 3.4</td>
<td>101.3 ± 4.4</td>
<td>0.023</td>
</tr>
<tr>
<td>ADC value (mm²/s)</td>
<td>(0.46 ± 0.01) × 10⁻³</td>
<td>(0.42 ± 0.008) × 10⁻³</td>
<td>(0.39 ± 0.006) × 10⁻³</td>
<td>0.003</td>
</tr>
</tbody>
</table>

The correlation between the related indexes of DWI MRI and DEXA T-scores:

It seems that there is a linear relationship between the T-score and ADC were also determined by using bivariate correlation and calculating the Pearson correlation coefficient (r).

A significant positive correlation was observed between the BMD and bone marrow ADC with r = 0.6388 and p < 0.0001. Figure (3.5).
Figure (3.5): The scatter plot shows the relationship between bone density represented by T-score and ADC value at L3 vertebral body.

We found also that there was a reverse linear relationship between the t-score and T1 value. T1 signal intensity tended to increase with reducing t-score values with a statistical significance with an $r = -0.193$ and $p < 0.005$. Figure (3.6)

Figure (3.6): The scatter plot shows the relationship between bone density represented by t-score and T1 value at L3 vertebral body.
**Figure (3.7):** 55 year female with Normal bone density. A) Shows diffusion value. B) Shows ADC value.

**Figure (3.8):** 68 year female with Osteopenia. A) Shows diffusion value. B) Shows ADC value.
DISCUSSION

In our study we found that bone marrow ADC correlates closely with BMD. The ADC values declined in line with a fall in BMDs. This direct relationship between ADC values and BMDs is likely a reflection of an increase in bone marrow fat content. Ward et al (19) and Nonomura et al (20) were in agreement that ADC values of presumed red (cellular) marrow were higher than those of yellow (fatty) marrow in their studies. Nonomura et al (20) further indicated that there was a positive correlation between ADC values and the cellularity of bone marrow.

Study Group Age:

In this study, we found that there was a significant association between the age of the patient and the BMD that was represented by t-score and ADC value of L3 vertebra, in a way that increasing the age of the patient associated with a lower t-score and ADC value, and this is compared to result of Turna O et al (21).

Diffusion and ADC Values:

We found that the values of the diffusion signal intensity at L3 vertebra represented as an (SNR value) were 134.5 ± 5.7, 112.7 ± 3.4, 101.3 ± 4.4 for normal, osteopenic, and osteoporotic group respectively. By comparing the values of the three groups, there was a significant

Figure (3.9): 65 year female with Osteoporosis. A) Shows diffusion value. B) Shows ADC value.
difference among the three groups (P = 0.023). These findings are close to those of Hatipoglu et al (22). Table (4.1)

Table (4.1): Comparison of the mean Diffusion values between normal, osteopenic, and osteoporotic subjects in the present and previous studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Hatipoglu et al (39)</th>
<th>Turna O et al. (43)</th>
<th>Present study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2007</td>
<td>2014</td>
<td>2017</td>
</tr>
<tr>
<td>Mean diffusion values(SNR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>131.5 ± 8.2</td>
<td>142.5±100.3</td>
<td>134.5 ± 5.7</td>
</tr>
<tr>
<td>Osteopenia</td>
<td>117.4±7.5</td>
<td>-</td>
<td>112.7 ± 3.4</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>99.5±5.4</td>
<td>76.26±37.32</td>
<td>101.3 ± 4.4</td>
</tr>
</tbody>
</table>

The values of ADC at L3 vertebra were (0.46 ± 0.01) × 10⁻³ mm²/s, (0.42 ± 0.008) × 10⁻³ mm²/s, and (0.39 ± 0.006) × 10⁻³ mm²/s for the three groups: the normal, osteopenic, osteoporotic respectively, which are near to those of other studies as shown in the table (4.2). Differences between different studies could be related to the use of different parameters in MRI protocols including different b values, and different patient’s demographics as those studies were applied in different countries, different races and ethnicities, and different life styles. There was significant difference in ADC values among the three groups (P = 0.003), this is similar to findings of previous studies (22-26).

Table (4.2): Comparison of the mean ADC values between normal, osteopenic, and osteoporotic subjects in the present and previous studies

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2006</td>
<td>2007</td>
<td>2010</td>
<td>2010</td>
<td>2014</td>
<td>2017</td>
</tr>
<tr>
<td>Mean ADC values(×10⁻³ mm²/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.46±0.08</td>
<td>0.47±0.08</td>
<td>0.47±0.03</td>
<td>0.47±0.03</td>
<td>0.49±0.03</td>
<td>0.46</td>
</tr>
<tr>
<td>Osteopenia</td>
<td>0.41±0.12</td>
<td>0.45±0.06</td>
<td>0.42±0.02</td>
<td>0.41±0.02</td>
<td>0.41±0.03</td>
<td>0.42</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>0.43±0.12</td>
<td>0.43±0.07</td>
<td>0.39±0.03</td>
<td>0.39±0.02</td>
<td>0.34±0.04</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Osteoporotic subjects in the present and previous studies
The correlation between the ADC and T1 values with DEXA t-scores:

There is a significant positive linear relationship between the t-score and ADC with \( r = 0.6388 \) and \( P < 0.0001 \). This is similar to the findings of Kumar et al.\(^{(27)}\) who found also a significant positive relationship with \( r = 0.895 \) and \( P < 0.001 \) and Liu et al.\(^{(25)}\) with \( r = 0.572 \) and \( P < 0.001 \) and Tang et al.\(^{(26)}\) with \( r = 0.835 \) and \( P < 0.001 \). Also, there is a reverse linear relationship between the t-score and T1 value. T1 signal intensity tended to increase with the decrease of t-score values with an \( r = -0.193 \) and \( p < 0.005 \). These results are comparable with those of Koyama H et al.\(^{(26)}\) who found also a significant reverse relationship between those two parameters with an \( r = -0.64 \), \( P < 0.001 \), and Hatipoglu et al.\(^{(22)}\) with an \( r = -0.559 \), \( P < 0.0001 \).

CONCLUSION

- Both diffusion and ADC values are significantly lower in subjects with older postmenopausal osteoporosis.
- There is a significant positive relationship between T score determined by DEXA and ADC value.
- There is a reverse correlation between t-score and T1 SNR value.

REFERENCES

دور تطبيق الرنين الانتشاري الموزون والصورة المبنية على (ت 1) لتشخيص مرض هشاشة العظام في العمود الفقري في النساء بعد انقطاع الطمث

الخلاصة

المقدمة: يُعرف مرض هشاشة العظام حالياً كمرض الهيكل العظمي الذي يتميز بانخفاض الكتلة العظمية وتدهور مكونات النسيج العظمي، ويتسبب على ذلك زيادة في ضعف العظام مع قابلية للكسر. هشاشة العظام ما بعد سن اليأس هي واحدة من أكثر الأسباب شيوعاً لمرض هشاشة العظام الأولي. تعنين من الزمان استخدام الفحص الانتشاري والموزون في الرنين المغناطيسي لتفحص الأمراض داخل الجمجمة، ولكن التقدم التكنولوجي جعل من الممكن تطبيق التصوير الانتشاري والموزون خارج الجمجمة بما في ذلك العمود الفقري.

الأهداف: استخدام تكنولوجيا التصوير بالرنين المغناطيسي الانتشاري والموزون لتحديد قيم الانتشار ومعامل الانتشار الواضح للفرع القطنية الثالثة في النساء بعد سن اليأس وتقييم روابطهما مع مقياس امتصاص الأشعة السينية ثنائي البواعث.

المرضى والطرق: تم إجراء دراسة تحليلية مقطعية في مستشفى اليرموك التعليمي في مدينة بغداد. وكان ما مجموعه 80 امرأة بعد سن اليأس، متوسط أعمارهم (63.2 سنة) تم تجميعها من الأشخاص الذين خضعوا لقياس امتصاص الأشعة السينية ثنائي البواعث في قسم الأشعة التشخيصية وتصنف إلى ثلاث مجموعات وفقاً للنتائج عامة إلى: كثافة عظم طبيعية، كثافة عظم قليلة، و هشاشة العظام. ثم إجراء دراسة التصوير بالرنين المغناطيسي لجميع المرضى متضمنة قياس مقياس امتصاص الأشعة السينية ثنائي البواعث (علامة (ت 1)، (ت 2)، الانتشار الموزون، معالج الانتشار الواضح.

النتائج: اجمالي عدد المرضى هو 80 امرأة، ذوي كثافة العظام الطبيعية كانت 28 حالة (55 - 72 سنة)، مجموعة قلة كثافة العظام 29 حالة (59-66 سنة)، وكانت مجموعة هشاشة العظام 32 حالة (65-79 سنة). وكانت قيم الانتشار الواضح في الفئة القطنية الثالثة (0.46 ± 0.098 × 10^3 ملم^2/ث)، حيث (0.39 ± 0.052 × 10^3 ملم^2/ث) لثلاثة مجموعات: الطبيعي، قلة كثافة العظام، و هشاشة العظام على التوالي. وكانت قيم الانتشار للموزون للثلاث مجموعات كالتالي: 134.5 ± 5.7 ملم^2/ث، 112.7 ± 4.4 ملم^2/ث، 51.3 ± 4.4 ملم^2/ث.

الاستنتاج: كل من قيمة الانتشار الموزون معالج الانتشار الواضح نسبياً مق قلة كثافة العظام في النساء بعد انقطاع الطمث، و هناك علاقة إيجابية ذات دالة إحصائية بين معالج الانتشار الواضح بين وعلامة (ت 1) التي تم تجميعها بواسطة جهاز القياس امتصاص الأشعة السينية ثنائي البواعث.