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 studywas 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 $(0.46 \pm 0.098) \times 10^{-3}$ mm^2/s, $(0.42 \pm 0.084) \times 10^{-3}$ mm^2/s, and $(0.39 \pm 0.052) \times 10^{-3}$ mm^2/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 mm^2/s, $112.7 + 3.4$ mm^2/s, $101.3 + 4.4$ mm^2/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) orbonemineral content (BMC) currently are used in the practicalbasis for the diagnosis of osteoporosis. [3,4,5]

Menopause is a natural physiological phenomenonresulting from primary ovarian failure secondary toapoptosis or programmed cell death.

At menopause the normal bone turnover cycle isimpaired by estrogen deficiency. Theosteoclasticresorption activity increases while the osteoblastic activitydecreases. As a result, the amount of bone resorbedexceeds the amount deposited, which leads to a netloss of bone.[6]

For the time being, the standard diagnosis of osteoporosis was dependent on the measurement of 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 ourlocal 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, anddementia. [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 informationcan 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]

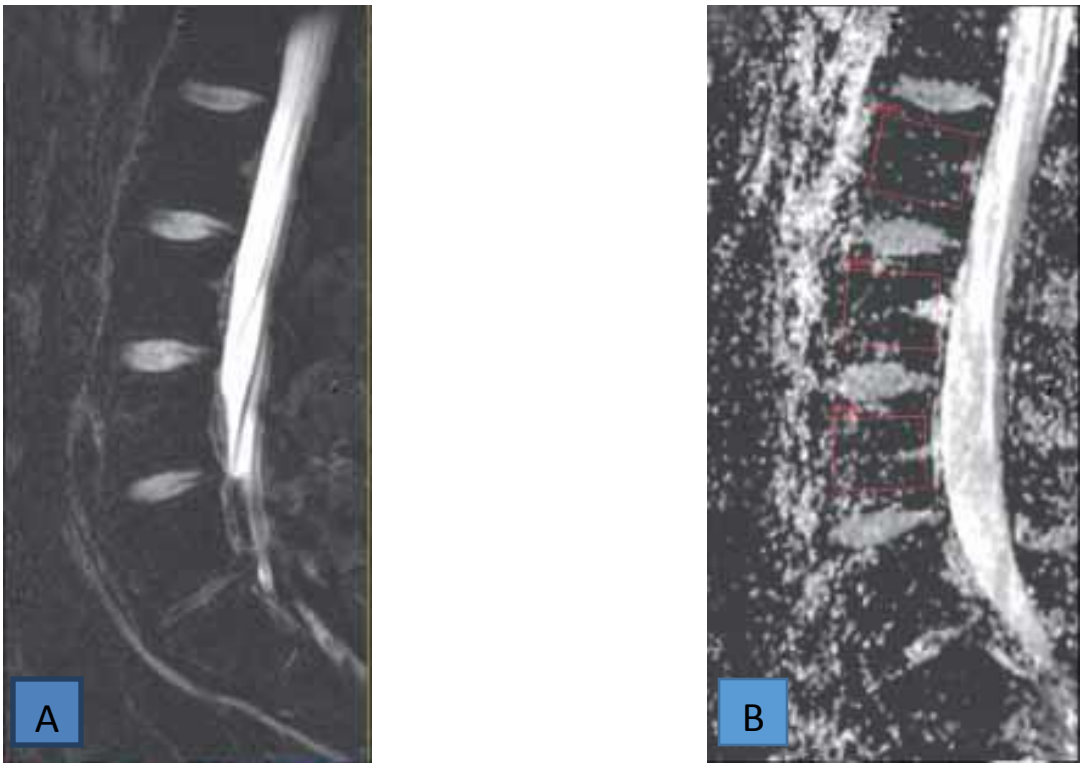

Figure (1.1): para sagittal MRI of lumbar spine A) Diffusion weighted image. B) Apparent diffusion coefficient (ADC) map.

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 80postmenopausal 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 affectBMD 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 Tl 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‐echoplanar imaging sagittal diffusion-weighted sequence at bvaluesof 0 and400 mm^2/s. Regions of interest (ROI) as circle of size 1 cm^2 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) $x10^{-3}mm^2/s$, 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.

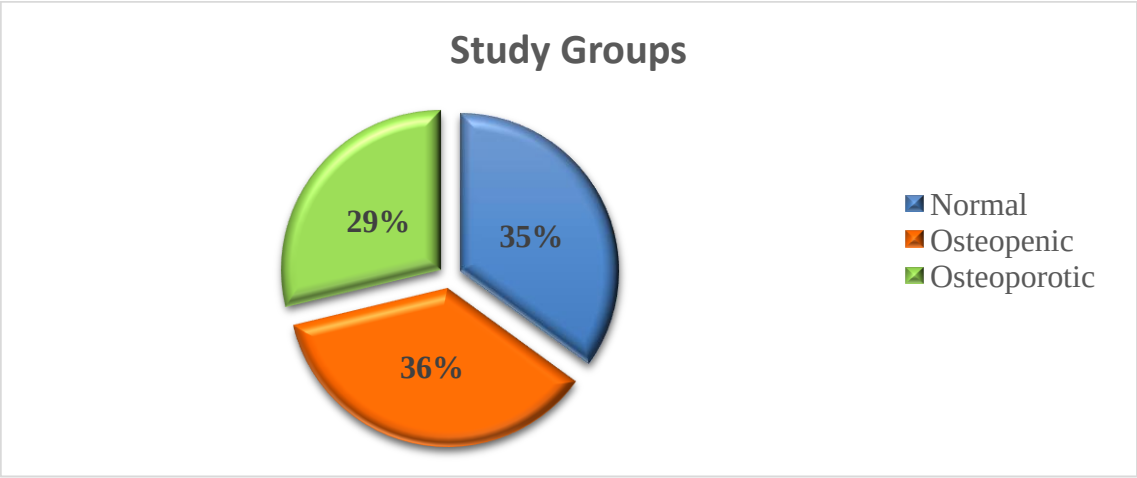

Figure (3.1): shows percentage of each study group

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.

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

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.

Age	**55-64 years**	**65-74 years**	**≥ 75 years**
Mean ADC value (mm^2/s)	**0.44 ± 0.01**	**0.41 ± 0.006**	**0.37 ± 0.008**
P value	**0.01**	**0.04**	**0.005**

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 atL3 vertebra *represented as an (SNR value)* were 134.5 ± 5.7, 112.7 ± 3.4, 101.3 ± 4.4respectively (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);

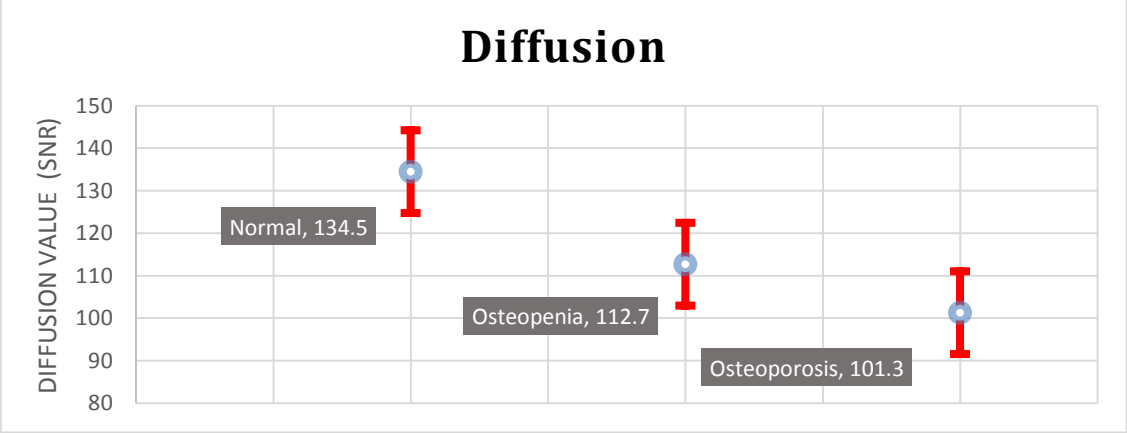

Figure (3.3): Graph shows diffusion values for normal, osteopenic, and osteoporotic groups.

The values of ADC atL3 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).

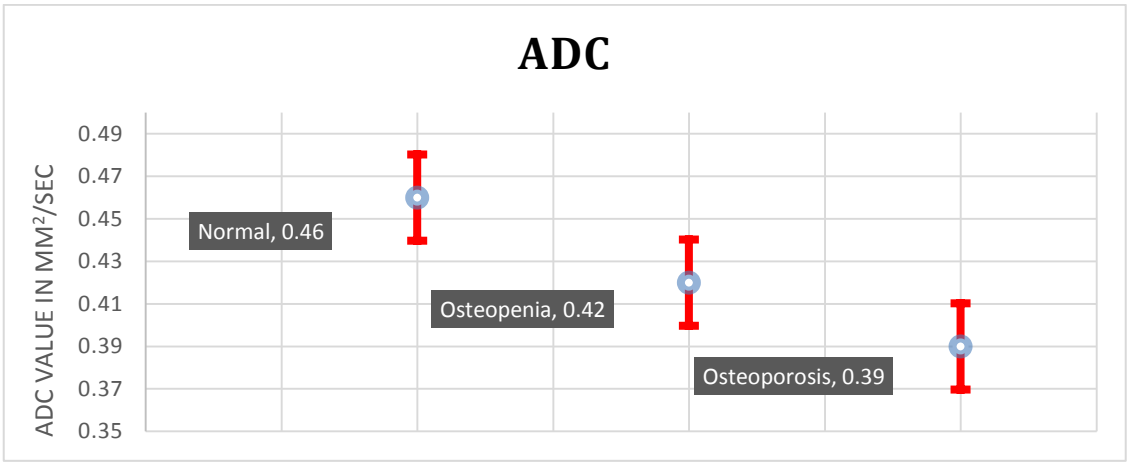

Figure (3.4): Graph shows ADC values for normal, osteopenic, and osteoporotic groups.

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

Parameter	Normal group	Osteopenic group	Osteoporotic group	P value
Diffusion (SNR)	134.5 ± 5.7	112.7 + 3.4	101.3 + 4.4	0.023
ADC value (mm2/s)	(0.46 ± 0.01) × 10^{-3}	(0.42 ± 0.008) × 10^{-3}	(0.39 ± 0.006) × 10^{-3}	0.003

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).

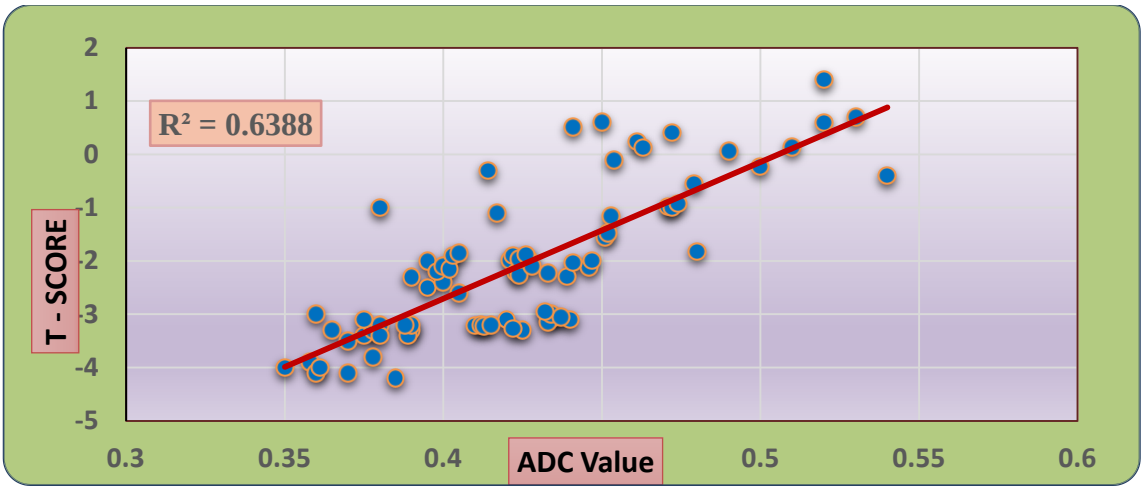

Figure (3.5): The scatter plot shows the relationship between bone density represented by T-score and ADC value at L3 vertebral body.

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)

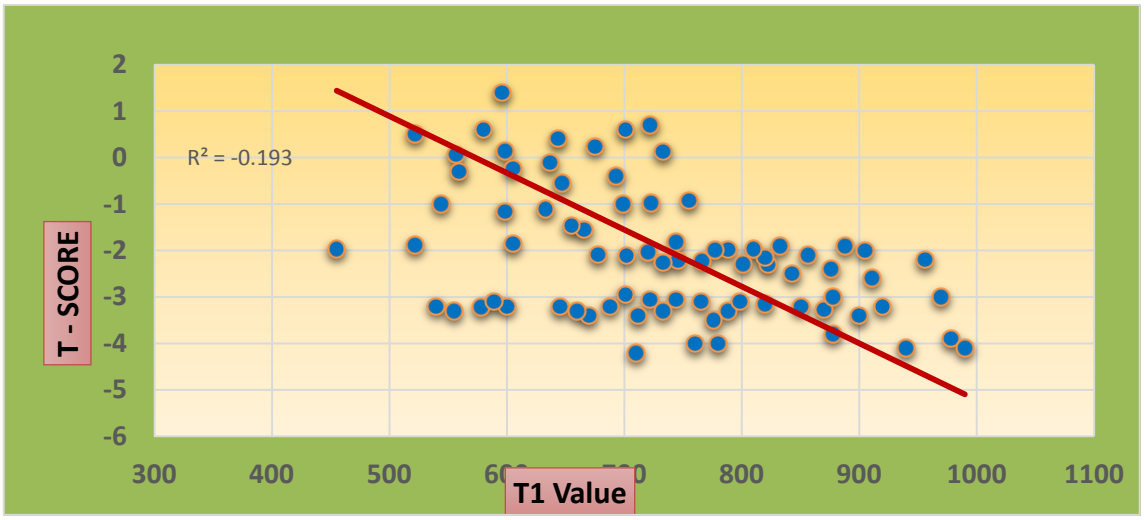

Figure (3.6): The scatter plot shows the relationship between bone density represented by t-score and T1 value at L3 vertebral body

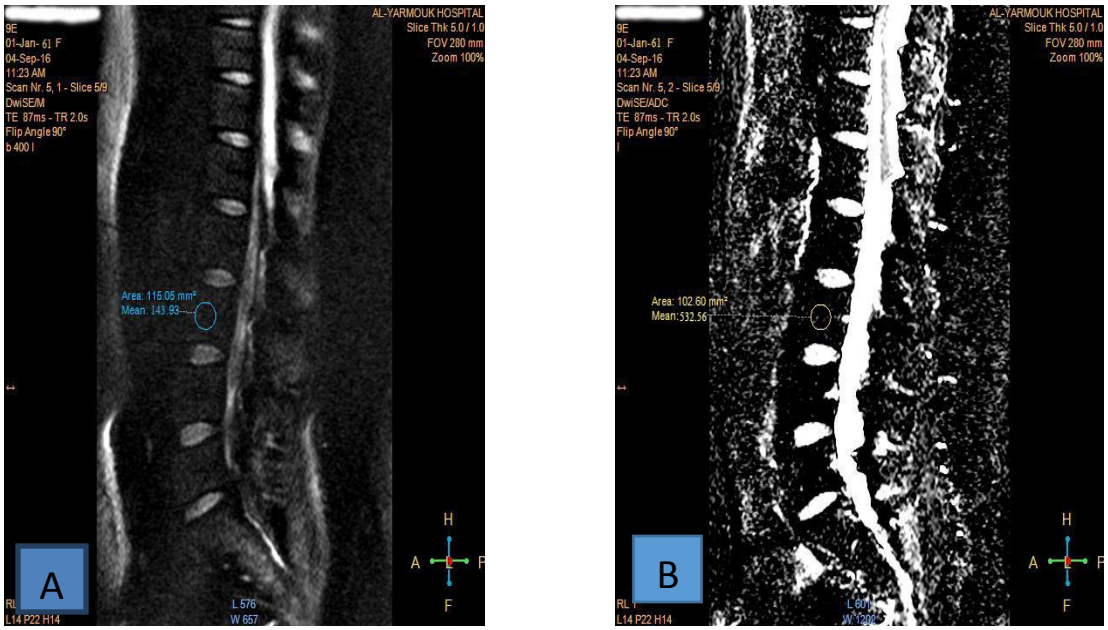

Figure (3.7): 55 year female with Normal bone density. A) Shows diffusion value. B) Shows ADC

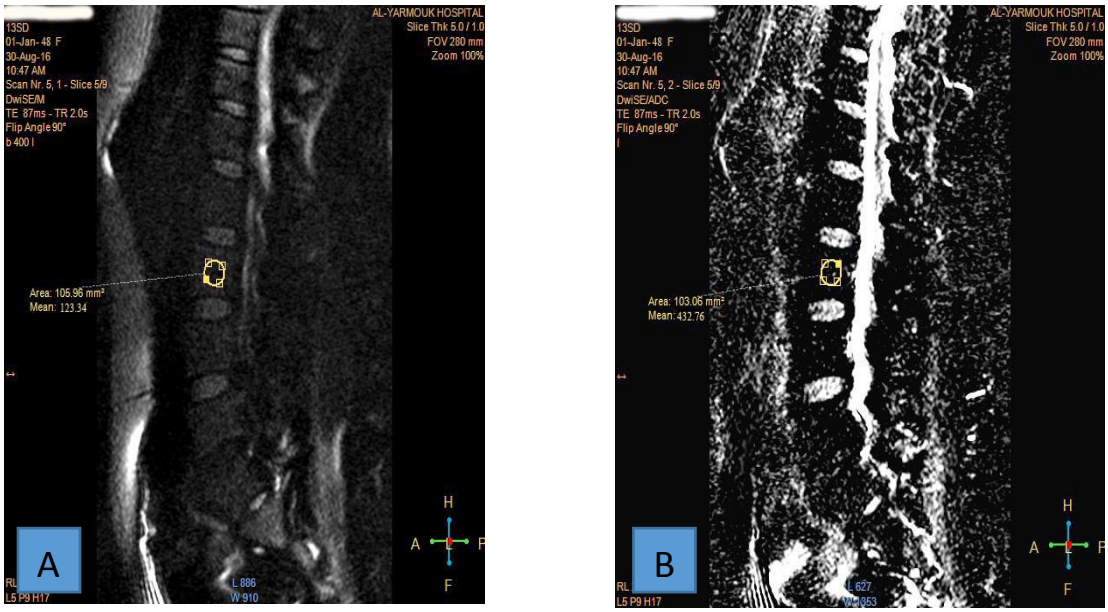

Figure (3.8): 68 year female with Osteopenia. A) Shows diffusion value. B) Shows ADC value.

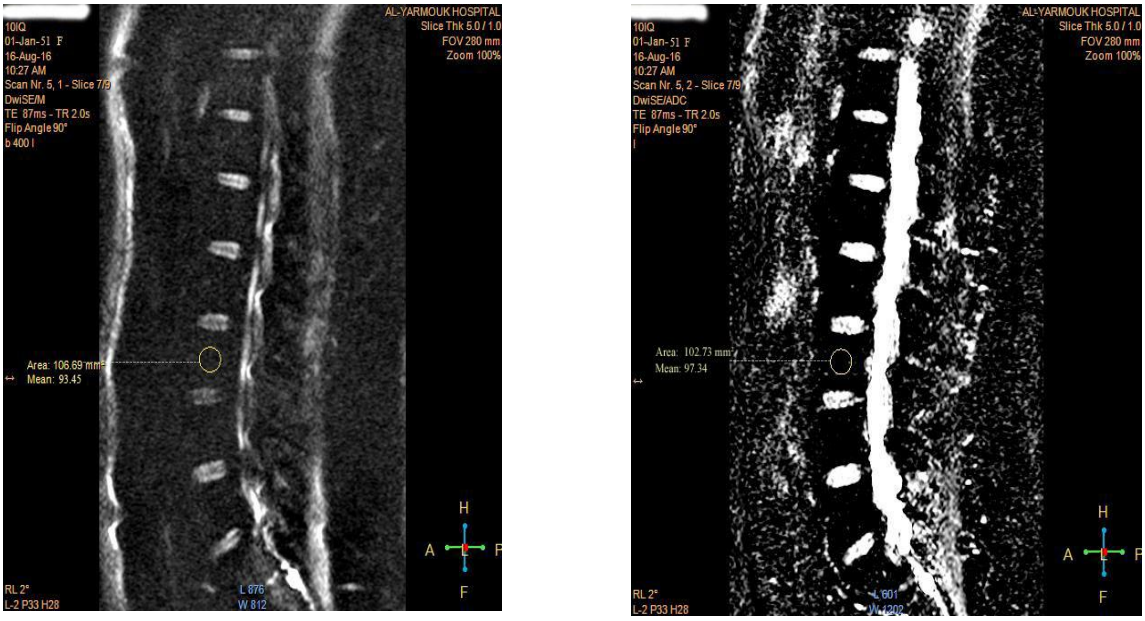

Figure (3.9): 65 year female with Osteoporosis. A) Shows diffusion value. B) Shows ADC value.

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 andBMDs is likely a reflection of an increase in bone marrowfat content. Ward et al[19] and Nonomura et al[20] were in agreement thatADC values of presumed red (cellular) marrow were higherthan those of yellow (fatty) marrow in their studies. Nonomuraet 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 ofTurna 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

difference among the three groups (P = 0.023).These findings are close to those ofHatipoglu et al [22]. Table (4.1)

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

Study	Hatipoglu et al [39])	Turna O etal.[43]	Present study
Year	2007	2014	2017
Mean diffusion values(SNR)			
Normal	131.5 ± 8.2	142.5±100.3	134.5 ± 5.7
Osteopenia	117.4±7.5	-	112.7 ± 3.4
Osteoporosis	99.5±5.4	76.26±37.32	101.3 ±4.4

The values of ADC atL3 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, 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

Study	Griffithetal.[28]	Fanuccietal.[36]	Liuetal.[37]	Tangetal.[38]	Kumar et al [33]	Present study
Year	2006	2007	2010	2010	2014	2017
MeanADC values(						
Normal	0.46±0.08	0.47±0.08	0.47±0.03	0.47±0.03	0.49±0.03	0.46
Osteopenia	0.41±0.12	0.45±0.06	0.42±0.02	0.41±0.02	0.41±0.03	0.42
Osteoporosi	0.43±0.12	0.43±0.07	0.39±0.03	0.39±0.02	0.34±0.04	0.39

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 ADCwith 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; P < 0.001 and Liu et al [25]withr = 0.572 and P < 0.001 and Tang et al [26] with r = 0.835; 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 those of Koyama *H* et al [26] who found also a significant reverse relationship between those to 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.

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دور تطبيق الرنين الانتشاري الموزون والصورة المبنية على (ت ١) لتشخيص مرض هشاشة العظام في العمود الفقري في النساء بعد انقطاع الطمث

١ ـ د. رعد حفظي الخياط, دكتوراه اشعة تشخيصية / استاذ مساعد كلية طب اليرموك
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الخلاصة

المقدمة: يعرف مرض هشاشة العظام حاليا كمرض الهيكل العظمي الذي يتميز بانخفاض الكتلة العظمية وتدهورمكونات النسيج العظمي، ويترتب على ذلك زيادة في ضعف العظام مع قابلية للكسر. هشاشة العظاممما بعد سن اليأس هي واحدة من أكثر الأسباب شيوعا لمرض هشاشة العظام الأولي. لعقدين من الزمنتم استخدام الفحص الانتشاريالموزون في الرنين المغناطيسي لتقييم الأمراض داخل الجمجمة، ولكن التقدم التقني جعل من الممكن لتطبيق التصوير الانتشاريالموزون خارج الجمجمة بما في ذلك العمود الفقري.

الاهداف: استخدام تكنولوجيا التصوير بالرنين المغناطيسي الانتشاريالموزون لتحديد قيم الانتشارومعامل الانتشار الواضح للفقرة القطنية الثالثة في النساء بعد سن اليأس وتقييم ارتباطها معمقياس امتصاص الأشعة السينية ثنائي البواعث (علامة t)

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 سنوات) تم تجنيده من الاشخاص الذين خضعوا مقياس امتصاص الأشعة السينية ثنائي البواعثللعمود الفقري في قسم الأشعة التشخيصية وتصنيفها إلى ثلاث مجموعات وفقا للنتيجة علامة tالى: كثافة عظم طبيعية، كثافة عظم قليلة، و هشاشة العظام. ثم تم اجراء دراسة التصوير بالرنين المغناطيسي لجميع المرضى متضمنة: ت1، ت2، الانتشار الموزون، معامل الانتشار الواضح.

النتائج: إجمالي عدد المرضى هو 80 امرأة، ذوي كثافه العظم الطبيعية كانت 28 حالة (55- 72 سنة)، مجموعة قلة كثافة العظم 29 حالة (59- 76 عاما)، وكانت مجموعة هشاشة العظام 23 حالة (56- 79 سنة). وكانت قيم معامل الانتشار الواضح في الفقرة القطنية الثالثة (0.46 ± 0.098) × 10^{-3}ملم^2 / ث، (0.42 ± 0.084) × 10^{-3}ملم^2/ ثانية، و (0.39 ± 0.052) × 10^{-3}ملم^2 / ث للثلاثمجموعات: الطبيعي ، قلة كثافة العظم، و هشاشة العظام على التوالي. وكانت القيم الانتشار الموزون للثلاث مجموعات كالتالي: 134.5 ± 5.7، 112.7 ±3.4، 101.3 ±4.4 على التوالي.
الاستنتاج: كل من قيمة الانتشار الموزونو معامل الانتشار الواضحتقل نسبيا مق قلة كثافة العظم في النساء بعد انقطاع الطمث. و هناك علاقة إيجابية ذات دلالة إحصائية بينمعامل الانتشار الواضح بين وعلامة t الذي تم تحديده بواسطة جهاز ال مقياس امتصاص الأشعة السينية ثنائي البواعث امتصاص الأشعة السينية ثنائي البواعث.