Articles

Comparison of bone mineral density with dual energy x–ray absorptiometry, quantitative ultrasound and single energy x–ray absorptiometry

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ABSTRACT

Objective: We conducted this prospective study to establish the correlation between dual energy x-ray absorptiometry (DXA), quantitative ultrasound (QUS) and single energy x-ray absorptiometry (SXA) and to establish the role of QUS and SXA as a screening tool for osteoporosis.

Methods: We carried out measurements of bone mineral density (BMD) of lumbar spine and femoral neck using DXA, QUS of heel using ultrasound densitometer, and BMD of forearm using SXA. We performed all the measurements at the Nuclear Medicine Division of King Khalid University Hospital, Riyadh, Kingdom of Saudi Arabia between 2002 and 2004. We obtained the measurements of 437 female adult patients, aged 20-87 years.

Results: We expressed all the values as mean $\pm$ SD. The BMD (g/cm^2) of lumbar spine was 1 ± 0.18, and femoral neck was 0.88 ± 0.17. The broad band ultrasound attenuation (BUA) of the heel was 74.9 ± 39.1 dB/MHz, the speed of sound (SOS) was 1542.5 ± 81.4 m/s, and the estimated BMD was 0.52 ± 0.15 (g/cm^2). The BMD of forearm showed a value of 0.44 ± 0.10 g/cm^2. The best correlation was between absolute values of BMD of lumbar spine and femoral neck (r=0.71, p=0.000). The

correlation between BMD of lumbar spine, QUS heel and forearm BMD was significant, but low to moderate (r=0.43-0.64, p=0.000). A strong correlation existed between the various parameters of heel, namely, BUA, SOS and estimated BMD (r=0.85-0.96, p=0.000). We used the World Health Organization (WHO) criterion of T-score to diagnose the patients with osteoporosis or osteopenia with each modality. We diagnosed a maximum number of patients to have osteoporosis with BMD estimation of lumbar spine (31%), followed by femoral neck (14%), forearm (11%), and heel (6%).

Conclusion: The correlation between all modalities was significant, but varied from high to low. It was high between lumbar spine and femoral neck, moderate between lumbar spine and forearm and low between lumbar spine and QUS of heel. When we used the same WHO criterion of T-score (more than -2.5 SD below normal), QUS detected significantly less numbers with osteoporosis. We conclude that with the present cut-off of T-score, the QUS may not be used as a screening tool. It may need some modification of T-score. However, we need larger multi-center studies with a larger number of patients for further validation.

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Progressive skeletal disorder characterized by low bone mass and deterioration of micro architecture of bones leading to increased bone fragility and susceptibility to fractures defines osteoporosis.[1] Osteoporosis is a major public health problem, occurring in every population and

geographic area studied.[2] According to the World Health Organization (WHO), osteoporosis is second only to cardiovascular diseases as a health care problem. In the USA, 24 million people, out of whom 80% are women, have osteoporosis. The fractures, a sequel of osteoporosis, carry a high mortality and morbidity, costing 18 billion US dollars in the USA, and 6.4 million pounds in the UK and Wales in 2001.[3] Hip fractures can rise from 1.7 million in 1990 to 6.3 million by 2050 with the most dramatic increase expected in Asia.[4] This holds true for Saudi Arabia, where the recent socio-economic progress and change in living conditions resulted in increased life expectancy. The bone mineral density (BMD) of the normal Saudi population is lower than the normal Caucasian US population.[5,6] This finding, coupled with high prevalence of low BMD in post menopausal women (osteoporosis 30.6%, osteopenia 39.5%), warrant good facility for screening and diagnosis of osteoporosis.[7] The non-invasive methods available to measure the BMD includes dual energy x-ray absorptiometry (DXA), single x-ray absorptiometry (SXA), quantitative ultrasound (QUS) and quantitative computerized tomography (QCT). The DXA has been the most extensively validated method, and is the gold standard for assessment of BMD. Studies have been conflicting and demonstrated that the diagnosis of osteoporosis can vary depending on which area of the body is screened, (namely, lumbar spine, hip, forearm or heel), equipment and reference data used. The United States Preventive Service Task Force (USPSTF) found that DXA of the hip is the best predictor of hip fracture, but we can also use bone density measurements of hand, wrist, forearm, and heel to detect the risk for osteoporotic fracture to some degree.[8] We undertook this prospective study to determine the correlation between DXA, QUS and SXA and possible validation of QUS and SXA to be used as screening tools.

Methods. A heterogeneous population of 437 consecutive adult females aged 20-87 years (mean 47 years) was recruited from the primary care clinics, employee health clinic, and relatives of employees and patients. All patients had their axial BMD, anteroposterior lumbar spine (L1-L4) and hip with GE prodigy (Lunar GE, Wisconsin USA), distal radius BMD on PIXI (Lunar GE, Radiation Corporation, Madison WI USA), and QUS of heel with Hologic (Sahara clinical Bone Sonometer, USA) measurements taken. The quality control procedures for all 3 machines were carried out every morning according to the protocol mentioned in the procedure manual. All patients had the 3 studies performed, processed and finalized for reporting on the same day. The automatic region of interest (ROI) was used in all procedures to calculate the

BMD of lumbar spine, femoral neck and heel. The manual adjustments in ROI were made for lumbar spine when necessary, for example, in cases of severe scoliosis. All the studies were performed at the Nuclear Medicine Division, King Khalid University Hospital, Riyadh, Kingdom of Saudi Arabia during 2002 to 2004, and reported by a nuclear physician.

The statistical analysis of the data was performed with SPSS software package. We used paired t-test to compare the values (results) of lumbar spine with femoral neck, forearm and heel. The comparison was carried out between femoral neck, forearm, and heel, and between forearm and heel. We assumed that there is statistically significant difference between these values if $p<0.05$. We also calculated the correlation co-efficient to find the relation between the values by Spearman's rank-difference correlation. The p value<0.05 was considered significant and very significant for $p<0.001$.

The lumbar spine, femoral neck and distal radius BMD and QUS estimated bone mineral density (estimated BMD) of heel was expressed as g/cm². The SD from the normal young adult value was used to calculate the T-Score for each procedure. The WHO criterion (T-Score) was used for the diagnosis of osteoporosis, osteopenia and normal. For osteoporosis, the cut off limit of more than -2.5 SD below normal adult was used. **Table 1** illustrates the WHO criteria for diagnosis of osteoporosis based on T-score. The broad band ultrasound attenuation (BUA) and speed of sound (SOS) were derived for heel with QUS (Sahara Sonometer), expressed as decibel/megahertz (dB/MHz.) and meter/second (m/s). The normal reference data provided with the respective machines were used for comparison with patient's values. This normal data were for young adult Caucasian US females.

Results. The values of BMD for lumbar spine, femoral neck, forearm, estimated BMD of heel, and the BUA and SOS of heel as mean values and SD, and comparison for statistically significant difference is shown in **Table 2.** The paired t-test found very significant differences since the $p<0.001$ for all comparisons. The Spearman's rank difference correlation was very significant, as $p<0.001$ for all values, but varied with variable correlation coefficient (r) between all modalities. The correlation of lumbar spine BMD was best with femoral neck BMD, followed by SXA, estimated BMD, BUA, and SOS, with no significant difference between BUA and SOS. The correlation coefficient (r) for all 3 modalities are given in **Table 3.** The number of persons diagnosed with osteoporosis, osteopenia and normal, were calculated for lumbar spine and femoral neck, forearm and heel. The DXA of lumbar spine

Table 1 - WHO definition of osteoporosis based on bone mass (density) measurements using DXA.

Definition	Criteria
Normal	BMD with in -1 SD of reference mean for young adults.
Low bone mass (osteopenia)	BMD with in -1.0 and -2.5 SD lower than reference mean for young adults.
Osteoporosis	BMD less than -2.5 SD lower than reference mean for young adults.
Severe osteoporosis	BMD as defined above with one or more fragility fractures.

*BMD - bone mineral density, SD - standard deviation, WHO - World Health Organization, DXA - dual energy x-ray absorptiometry

Table 4 - The number of osteoporosis, osteopenia and normal cases from 437 patients.

Site	Osteoporosis n=437 (%)	Osteopenia n=437 (%)	Normal n=437 (%)
L1-L4 (DXA)	136 (31)	156 (36)	145 (33)
Femoral Neck (DXA)	62 (14)	153 (35)	222 (51)
Heel (Est. BMD)	26 (6)	130 (30)	281 (64)
Forearm (SXA)	50 (11)	148 (34)	239 (55)

SXA - single energy x-ray absorptiometry, Est. BMD - estimated bone mineral density, DXA - dual energy x-ray absorptiometry

Table 2 - Mean values with SD and comparison between values for 437 subjects

Site	BMD ± SD (g/cm^2)	BUA ± SD (dB/MHz)	SOS ± SD (m/s)
Lumbar spine (DXA) *,**†	1 ± 0.18	--	--
Femoral neck (DXA) *††‡	0.88 ± 0.17	--	--
Forearm (SXA) **††‡‡	0.44 ± 0.10	--	--
Heel (ultrasound densitometer) †‡,‡‡	0.52 ± 0.15	73.78 ± 20.9	1539.08 ± 106.02

* - There is significant difference between lumbar spine and femoral neck since $p<0.05$, ** - There is significant difference between lumbar spine and forearm since $p<0.05$, † - There is significant difference between lumbar spine and heel since $p<0.05$, †† - There is significant difference between femoral neck and forearm since $p<0.05$, ‡ - There is significant difference between femoral neck and heel since $p<0.05$, ‡‡ - There is significant difference between forearm and heel $p<0.05$, SXA - single energy x-ray absorptiometry, DXA - dual energy x-ray absorptiometry, BMD - bone mineral density, BUA - broad band ultrasound attenuation, SOS - speed of sound, SD - standard deviation.

Table 3 - Correlation coefficients (r) of absolute measured values for 437 subjects.

Region	L1-L4	Femoral neck	Forearm SXA	Heel Est. BMD	Heel BUA	Heel SOS
L1-L4 (DXA)	1	0.71	0.64	0.46	0.43	0.43
Femoral Neck (DXA)	0.71	1	0.65	1.46	0.44	0.41
Forearm (SXA)	0.64	0.65	1	0.58	0.55	0.54
Heel (Est. BMD)	0.46	0.46	0.58	1	0.92	0.96
Heel (BUA)	0.43	0.44	0.55	0.92	1	0.85
Heel (SOS)	0.43	0.41	0.54	0.96	0.85	1

p value was very significant for all comparisons being <0.001, (Significant $p<0.05$ and very significant $p<0.001$, SXA - single energy x-ray absorptiometry, Est. BMD - estimated bone mineral density, BUA - broad band ultrasound attenuation, SOS - speed of sound, DXA - dual energy x-ray absorptiometry

diagnosed 31% of the examined population with osteoporosis, 36% with osteopenia and 33% as normal. The details of patients with osteoporosis, osteopenia and normal diagnosed by all modalities at different measured sites are given in **Table 4.**

Discussion. Osteoporosis is the condition that occurs when the bone tissue thins or develops holes, can cause pain, broken bones and loss of body height. Still usually, it is a silent disease, diagnosed at the occurrence of the fracture. To reduce the number of osteoporotic fractures and lessen the socio-economic burden on society, the early diagnosis of osteoporosis is essential. Although, the DXA BMD measurement at femoral neck is the best in predicting hip fractures, it is comparable with forearm measurement for predicting fractures at other sites. Some prospective studies evaluated the QUS measurement of heel.[9-10] The QUS of heel is encouraged as calcaneus and spine are both made up largely of trabecular bone and estimation of calcaneus BMD may be used to predict the risk of spinal fracture. However, Gregg et al[11] showed moderate correlation between QUS and DXA. We determined the correlation between BMD of spine and femoral neck (DXA), BMD of forearm (SXA), and BUA, SOS, estimated BMD of heel. Generally, the best correlation existed between DXA BMD of lumbar spine (L1–L4), and femoral neck (r=0.71, *p*<0.001). This report agrees with the reported correlation of spine and hip by Young et al[12] (r 0.67). The correlation of DXA BMD of lumbar spine with heel BUA (0.43), SOS (0.43), estimated BMD (0.46) was significant (r<0.001) but low. Cresten et al[13] reported the similar results for BUA (r=0.44) and lower correlation for SOS (r=0.11). This may be attributed to statistical analysis used, as when the Pearson correlation was used our results were comparable for SOS correlation (r=0.11).

Poet et al[14] found a higher correlation between BUA and lumbar spine DXA (r=0.81), which is significantly higher than our study. However, the number of patient studied with DXA was small (n=15), in comparison to the higher number in our study. Moreover, they did not ascertain any significant difference between BUA of normal and osteoporotic patients, rendering use of BUA not valuable in clinical practice. Moris et al[15] also published a higher correlation of lumbar spine DXA with BUA (r=0.57) and SOS (r=0.67). This moderate correlation between QUS and DXA reported in different studies was attributable to the physiological and anatomical differences between different bone sites measured, and their different aging process.[16] A very strong correlation existed between various parameters of QUS measurements. The highest between estimated BMD with BUA (r=0.92) and SOS (r=0.96), also between BUA and

SOS (r=0.85). This was in accordance with the fact that estimated BMD is derived from SOS, while BUA and SOS are determined at one site, namely, calcaneus with the same equipment and the same reference data. Moderate significance correlation was found between lumbar spine DXA and forearm BMD by SXA (r=0.65).

The prevalence of osteoporosis in the studied population was calculated according to the WHO cut off (-2.5 SD) T-score for DXA measurement of lumbar spine and femoral neck, ultrasound estimated BMD of heel, and SXA measurement of forearm. The normal data provided from the manufacture were used for the calculation of T-score. This normal data was for normal adult Caucasian US females, which was slightly higher than the corresponding Saudi population but statistically not significant for T-score calculation.[5] The data for Saudi population have been published in 2 studies, but from Riyadh only, and may not represent the whole of the Saudi Arabian population.[5,6] The maximum number of patients with osteoporosis was diagnosed through DXA BMD measurement of lumbar spine. Hence, the best site for measurement of BMD according to our study was lumbar spine followed by femoral neck, distal radius, and calcaneus. The higher number of osteoporotic patients diagnosed by BMD measurement can be attributed to the fact that the spine detects a greater proportion of patients with osteoporosis than the hip or the forearm in early menopause. At age 70 or beyond, more patients were detected by both hip and forearm than by spine.[17] The same appears to be factor in our study as only 17 out of 437 patients were more than 70 years of age. Frost et al[18] reported higher numbers of patient diagnosed with osteoporosis by lumbar spine. Some other studies also concluded that the lumbar spine is more sensitive in assessment of the risk of osteoporosis compared to the femoral neck.[19] The high prevalence of osteoporosis (55.8%) reported by Martin[20] is due to the fact that the patient population was post menopausal ≥60 years old, which also has a high prevalence of osteoporosis, and the lumbar spine is favored as the best site. The controversy still exists regarding which site is the best for the assessment of osteoporosis risk. The National Health and Nutritional Examination Survey (NHANES III) used DXA measurement at the proximal femur to predict the hip fractures.[21] This was based on the studies showing proximal femur as the best site for the prediction of hip fracture, the osteoporotic fracture with greatest consequences in term of morbidity, mortality and cost. Although in the clinical setting, it is important to have BMD measurement of the lumbar spine, especially in patients with spine fractures, however, the femur

was considered the best site for screening purposes, as the hip fractures are important from a societal prospective, namely, the social and economic burden on society.

In the study, the QUS estimated BMD of heel showed few patients with osteoporosis comparable with the results of Frost et al.[18] They concluded that the strict application of a present cut off threshold of -2.5 may not be appropriate for QUS estimated BMD. Rather they suggested a lower cut off of -1.9 SD applied to estimated BMD. When we applied the same cut-off (-1.9 SD below normal adult) the percentage of diagnosed patients improved from 6-14%, which is equal to femoral neck. Marin et al[20] also calculated the cost for osteoporotic patients detected by DXA at -23.85 and for QUS at -22, which is not significantly different.

Generally, our results were in comparison with published studies that if the same T-score criteria were used for QUS and DXA, QUS would diagnose less number of patients with osteoporosis or osteopenia.

We conclude that the best site for the diagnosis of osteoporosis with DXA BMD is the lumbar spine. Significant and higher correlation exists between DXA measurement at lumbar spine, femoral neck and SXA measurement at forearm. There is a significant, but low correlation between lumbar spine DXA and QUS, resulting in fewer patients of osteoporosis diagnosed. Therefore, the QUS with a WHO cut off of -2.5 may not be used as screening or diagnosis; either improvement in equipment/ software or modification in T-score is needed for QUS. More multi-centre studies, with larger data are necessary to establish the role of QUS and SXA in local settings.

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