Bone Mineral Density—Correlation between Quantitative Ultrasound Characteristics and Dual Energy X-ray Absorptiometry

D C E Ng,*MBBS, MRCP, F X Sundram,**FAMS, MBChB, MSc (Nucl Med)

Abstract

The speed of sound (SOS) and the broadband ultrasound attenuation (BUA), as determined by quantitative ultrasound at the calcaneum, were correlated with the bone mineral density (BMD) measurements using dual-energy X-ray absorptiometry at the femoral neck and the lumbar spine in 110 females. There were moderate correlations of 0.629, 0.623 and 0.594 between the BMD at the anterior-posterior lumbar spine, lateral lumbar spine and femoral neck with the SOS at the calcaneum (all P <0.001). The corresponding correlations with BUA were 0.646, 0.643 and 0.628 respectively (all P <0.001). This suggests that quantitative ultrasound may be reasonably accurate and useful for the assessment of osteoporosis.

***Ann Acad Med Singapore* 1998; 27:524-6**

Key words: Dual energy X-ray absorptiometry, Hip length axis, Osteoporosis, Velocity of sound

Introduction

Osteoporosis is well documented to be a significant determinant of the risk of fracture and its assessment *in vivo* has been based on various methods for measuring bone mineral density (BMD). Dual-energy X-ray absorptiometry (DXA) has proven so far to be reasonably precise (about 1% to 2%) and accurate (about 5%).[1] However, it suffers from a lack of portability and exposure to radiation (albeit small amount). On the other hand, quantitative ultrasound has been shown to be useful in predicting the risk of hip and vertebral fractures.[2,3] Furthermore, ultrasound may be able to assess, in addition to the bone mineral density, the structural and biomechanical properties of bone that contribute to bone strength. *In vitro* studies such as those by Njeh et al[4] and Bouxsein et al[5] have reported a significant correlation of 0.82 and 0.71 respectively between ultrasound velocity and ultimate strength of the human calcaneum. In this study, ultrasound velocity and broadband ultrasound attenuation were correlated with BMDs obtained by dual-energy X-ray absorptiometry for a local population to determine the degree of correlation as an initial step in the evaluation of the quantitative ultrasound for the assessment of osteoporosis and fracture.

Materials and Methods

Female volunteers were recruited from among hospital staff and their relatives. Their particulars (names, age, gender, race, height, weight, medical and medication history) were recorded. The speed of sound (SOS) and the broadband ultrasound attenuation (BUA) were measured by a single operator on the left heel using the Hologic Sahara bone sonometer. Contact between the heel and the emitting and receiving transducers of ultrasound was achieved with ultrasound gel. The sonometer was calibrated with a standardised phantom daily. The reported precision of quantitative ultrasound in measurements of speed of sound ranged from 0.3% to 0.5% (coefficient of variation) and in measurements of BUA from 2.0% to 4.0% (coefficient of variation).[6] At the same sitting, measurement of bone mineral density of the left femoral neck and lumbar spine (anterior-posterior and lateral) by dual energy X-ray absorptiometry using the Hologic QDR4000 system was done, giving BMD results (in g/cm^2) which were correlated with SOS and BUA. Prior to this study, a study of bone mineral density measured using DXA in 227 normal females of the local population had been done.

Results

A total of 110 volunteers (all females) were included in this study. Their ages ranged from 18 to 83 years with a median of 52 years (SD = 15.2 years). 73.6% were Chinese, 10.9% Malays, 12.7% Indians and 2.8% of other races. Mean and standard deviation of measured variables are shown in Table I. BMDs were correlated with

* *Registrar*
** *Senior Consultant*
Department of Nuclear Medicine
Singapore General Hospital
Address for Reprints: Dr David Ng, Department of Nuclear Medicine, Singapore General Hospital, 1 Hospital Drive, Singapore 169608.

TABLE I: VARIOUS PARAMETERS MEASURED IN THIS STUDY

Variable	Mean	SD	Max	Min
Age (y)	50.9	15.2	83	18
Hip axis length (cm)	10.52	0.65	12.52	8.82
SOS (m/s)	1544.0	32.4	1615.9	1464.8
BUA (dB/MHz)	63.86	18.31	99.7	1.5
BMD (hip) (g/cm^2)	0.728	0.150	1.216	0.330
BMD (AP spine) (g/cm^2)	0.900	0.180	1.528	0.497
BMD (lat. spine) (g/cm^2)	0.643	0.136	0.984	0.295

SD: standard deviation; SOS: speed of sound; BUA: broadband ultrasound attenuation; BMD: bone mineral density; AP:anterior-posterior; lat.: lateral

TABLE II: CORRELATION COEFFICIENTS BETWEEN SOS, BUA AND BMD

r	Speed of sound	BUA
femoral neck BMD	0.594*	0.628*
spine (AP) BMD	0.629*	0.646*
spine (lat.) BMD	0.623*	0.643*

* P <0.001
SOS: speed of sound; BUA: broadband ultrasound attenuation; BMD: bone mineral density; AP:anterior-posterior; lat.: lateral

the SOS and BUA at the calcaneum and are shown in Table II.

Discussion

The present study shows a significant correlation of moderate degree between SOS and BMD measured by DXA. Comparable correlations are noted with a study by Cunningham which reported a r value of 0.470 between SOS and BMD of the spine and 0.498 between SOS and BMD of the femoral neck.[7] A recent review by Njeh,[6] summarising 3 and 4 published results respectively, showed comparable correlations of 0.48 to 0.55 between SOS and BMD of the spine and 0.35 to 0.65 between SOS and the femoral neck BMD.

The moderate correlation between velocity of sound and BMD (measured using DXA) has been attributed to reasons such as poorer precision of ultrasound (which is reported to be in the range of 1.6% to 10%), as well as bone factors. In particular, it has been argued that velocity may be dependent not only on bone density but on bone microarchitecture as well. This would include such aspects of bone as trabecular orientation, number, spacing, thickness and connectivity. An alternative way of stating the above is to say that bone microarchitecture determines the elastic modulus of bone relative to its density. In theory, since sound wave velocity in bone is roughly related to the square root of the ratio of the elastic modulus and density, this suggests that the relation between velocity and density may not be linear. Therefore the correlation may be expected to be only fair. Furthermore, the rather large reported variation in the r value could be due to different ultrasound systems used, different age-ranges and population groups studied.

Published correlations between BUA and BMD of the spine ranged from 0.35 to 0.83. This is based on the 8 studies reviewed by Njeh.[6] Similarly, the correlations between BUA and BMD of the femur ranged from 0.32 to 0.87 based on 7 studies. A large screening study of osteoporosis in 1000 perimenopausal women reported a best value of r = 0.354 for BUA and trochanter BMD.[8] An American study gave a correlation of 0.49 between BUA and spine BMD and 0.52 between BUA and femoral neck BMD.[3] Results of this study are approximately of similar order of magnitude.

The moderate correlation between BUA and BMD (DXA) has been thought to be accounted for by ultrasound precision errors as well as intrinsic bone characteristics as mentioned above. In cancellous bone, which makes up about 90% of the calcaneum, ultrasound attenuation is largely due to scattering, rather than by absorption. As scattering is highly dependent on bone micro-parameters such as anisotropy, it is highly plausible that ultrasound may measure bone features other than bone mass which is measured by DXA, and therefore BUA may be an independent predictor of fracture. Indeed, a study by Bauer[2] showed that after adjusting for bone mineral density of the femoral neck, BUA of the calcaneum was still associated with an increased risk of hip fracture, with a relative risk of 1.5. A meta-analysis of bone mass measurements in predicting the risk of fracture showed that ultrasound of the calcaneus could predict hip and vertebral fractures with comparable probability as non-ultrasound methods at the hip and lumbar spine.[9]

Locally, the incidence of hip fractures has increased from 0.7 per 1000 women who were 60 years of age and older in 1957 to 1962, to 1.5 per 1000 women in 1985.[10] A worldwide projection of hip fractures in the elderly predicts that the incidence of hip fractures in Asia will increase dramatically to 3 times the figure for 1990 (giving a figure of more than 1.5 million cases) by the year 2025, as a result of an ageing population.[11] Osteoporotic fractures constitute a major medical burden for the elderly and a public health burden for the community. A portable and accessible method of assessing bone and predicting fracture risk would be of some advantage in addressing this increase. This study suggests that in the local population, quantitative ultrasound is significantly correlated with bone mineral density measurements by DXA and may be useful as a modality in the assessment of osteoporosis and fracture risk.

Acknowledgement

The authors are grateful for the technical expertise provided by Mr Somanesan and Mr Philip Hoon for this study.

REFERENCES

1. Cooper C, Aihie A. Osteoporosis: recent advances in pathogenesis and treatment. Q J Med 1994; 87:203-9.
2. Bauer D C, Gluer C C, Cauley J A, Vogt T M, Ensrud K E, Genant H K, et al. Broadband ultrasound attenuation predicts fractures strongly and independently of densitometry in older women. A prospective study. Arch Intern Med 1997; 157:629-34.
3. Funke M, Kopka L, Vosshenrich R, Fischer U, Ueberschaer A, Oestmann J-W, et al. Broadband ultrasound attenuation in the diagnosis of osteoporosis: correlation with osteodensitometry and fracture. Radiology 1995; 194:77-81.
4. Njeh C F, Hodgskinson R, Langton C M. Determination of bone strength from ultrasonic velocity and broadband ultrasound attenuation. Br J Radiol 1995; 68:789-90.
5. Bouxsein M L, Radloff S E, Hayes W C. Quantitative ultrasound of the calcaneus reflects trabecular bone strength, modulus and morphology. J Bone Miner Res 1995; 10:S175.
6. Njeh C F, Boivin C M, Langton C M. The role of ultrasound in the assessment of osteoporosis. Osteoporosis Int 1997; 7:7-22.
7. Cunningham J L, Fordham J N, Hewitt T A, Speed C A. Ultrasound velocity and attenuation at different sites compared with bone mineral density measured using dual-energy X-ray absorptiometry. Br J Radiol 1996; 69:25-32.
8. Massie A, Reid D M, Porter R W. Screening for osteoporosis: Comparison between dual-energy X-ray absorptiometry and broadband ultrasound attenuation in 1000 perimenopausal women. Osteoporosis Int 1993; 3:107-10.
9. Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fracture. BMJ 1996; 312:1254-9.
10. Lau E M C, Cooper C. The epidemiology of osteoporosis. Clin Orthop 1996; 323:65-74.
11. Cooper C, Campion G, Melton L J. Hip fractures in the elderly: A worldwide projection. Osteoporosis Int 1992; 2:285-9.