Osteoporos Int (2000) 11:354–360

Osteoporosis International

Original Article

Assessment of a New Quantitative Ultrasound Calcaneus Measurement: Precision and Discrimination of Hip Fractures in Elderly Women Compared with Dual X-ray Absorptiometry

Y. Q. He, B. Fan, D. Hans, J. Li, C. Y. Wu, C. F. Njeh, S. Zhao, Y. Lu, E. Tsuda-Futami, T. Fuerst and H. K. Genant

Osteoporosis and Arthritis Research Group, Department of Radiology, University of California, San Francisco, California, USA

Abstract. The incidence of osteoporotic hip fracture increases in postmenopausal women with low hip bone mineral density (BMD). Dual X-ray absorptiometry (DXA) is the most commonly used technique for the assessment of bone status and provides good measurement precision. However, DXA affords little information about bone architecture. Quantitative ultrasound (QUS) systems have been developed to evaluate bone status for assessment of fracture risk. Our study was designed to assess a new QUS system from Hologic, the Sahara; to compare it with a previous model, the Walker-Sonix UBA 575+; and to investigate whether it is able to discriminate between women with and without fracture. Using both ultrasound devices, the measurements were performed at the heels of 33 postmenopausal women who had recently sustained hip fracture. A control group of 35 age-matched postmenopausal women was recruited for comparison. The total, neck and trochanter femoral BMD values were assessed using DXA for both groups. QUS and DXA measurements were significantly lower in fractured patients ($p<0.005$) than in the control group. The short-term, mid-term and standardized short-term precisions were used to evaluate the reproducibility of the two QUS systems. The Sahara showed a better standardized coefficient of variation for broadband ultrasound attenuation (BUA) than did the UBA 575+ ($p<0.001$). The correlation of BUA and speed of sound (SOS) between the two QUS devices was highly significant, with an r value of 0.92 for BUA and 0.91 for SOS. However, the correlation between DXA and ultrasound parameters ranged from 0.28 to 0.44. We found that ultrasound measurements at the heel were significant discriminators of hip fractures with odds ratios (OR) ranging from 2.7 to 3.2. Even after adjusting the logistic regressions for total, neck or trochanter femoral BMD, QUS variables were still significant independent discriminators of hip fracture. The areas under the ROC curves of each ultrasound parameter ranged from 0.75 to 0.78, and compared very well with femoral neck BMD ($p>0.05$). In conclusion, our study indicated that the calcaneal QUS variables, as measured by the Sahara system can discriminate hip fracture patients equally as well as hip DXA.

Keywords: Bone density; Hip fracture; Osteoporosis; Quantitative ultrasound

Correspondence and offprint requests to: C. F. Njeh PhD, OARG, Department of Radiology, 350 Parnassus Ave, Suite 908, University of California, San Francisco, CA 94143-1349, USA.

Introduction

The incidence of hip fracture increases in women after menopause. Osteoporosis, which is a major cause of fractures in elderly women, increases with age. There is an estimated 16.8 million (54% of all white women $\geqslant 50$ years of age) postmenopausal white women in the United States with osteopenia and another estimated 9.4 million (30% of all white women $\geqslant 50$ years of age) with osteoporosis [1]. It has been estimated that more than 250 000 hip fractures occur annually. At least 90% of these fractures happen in elderly white women with osteoporosis [1–3]. Accordingly, osteoporotic hip fractures will increase in the future along with the aging

population. Dual X-ray absorptiometry (DXA) is a highly precise technique and is the most commonly used method for assessing bone mass. However, DXA determines only bone mass, which explains 60–90% of bone strength, but provides little information on bone microarchitecture and bone elasticity [4–7].

Quantitative ultrasound (QUS) systems have been under development for more than 10 years by different manufacturers. This approach has been established as a safe and cost-efficient diagnostic method. It seems to provide information not only about bone mineral density (BMD) but also about the microarchitecture and elasticity of bone [8–11]. These characteristics of QUS may enhance the prediction of fracture risk compared with bone densitometry. The prospective study of Osteoporotic Fracture (SOF) demonstrated that QUS using a water-based system, the Walker-Sonix UBA 575+ (Hologic, Waltham, MA), was able to predict vertebral and hip fracture [12–15]. However, it has been reported that the measurement precision was less than satisfactory. The short-term coefficient of variation of broadband ultrasound attenuation (BUA) ranged from 2.3% to 6.64% [11,16]. The reported factors affecting QUS precision have included immersion time, water depth, water temperature, the concentration of a detergent wetting agent and foot positioning [17]. Recently, a new QUS scanner, the Sahara Clinical Bone Sonometer, has been developed by Hologic based on the older UBA 575+. The objective of this study was to evaluate this new QUS scanner and assess its ability to discriminate between patients with and without hip fracture.

Materials and Methods

Subjects

Sixty-eight postmenopausal Caucasian women aged 52–94 years (mean age 74.8 $\pm$ 7.2 years) living in the San Francisco Bay area were recruited for this study by newspaper advertisements. Of the 68 subjects, 33 women aged 74.5 $\pm$ 8.1 years were identified by history and medical records to have sustained hip fractures within the last 3 years and were used as the fracture group. The mean time since sustaining the hip fracture was 21.8 $\pm$ 9.2 months. Subjects were included in the fracture group only if the fracture resulted from a fall from standing height or less and involved no motion greater than walking. The fracture patients participating in the study had recovered from the fracture and were able to walk freely without walkers or help from others. For comparison, 35 women aged 75.7 $\pm$ 5.6 years with no hip fractures were used as the control group. All the women had ceased menstruating at least 6 months prior to the investigation. Menopause was defined as the time after the last menstruation. For each subject, height, weight and body mass index (BMI = weight/height^2) were obtained. The medical history of all participants was verified by telephone survey. Women with hormone replacement therapy for more than 6 months within the last 10 years, Paget's disease of the bone, juvenile diabetes, renal failure, or malignant disease with metastatic tumor were excluded from this study. We also excluded women who had taken calcitonin, bisphosphonates, anabolic steroids, fluoride or parathyroid hormone for more than 3 months within the last 3 years. The University of California, San Francisco Committee on Human Research approved the study protocol, and written informed consent was given by all study participants.

Ultrasound Measurements

The QUS measurements were obtained using the Sahara and UBA 575+, both from Hologic. For each subject, we carried out the Sahara measurement first, then waited 15 minutes cleaning the measured heel with alcohol pat, before measuring with the UBA 575+. The Sahara is a fully portable ultrasound system for measurement of the calcaneus using gel as a coupling agent. The range of BUA observed with the Sahara in a typical population is approximately 30–130 dB/MHz. It has two 19 mm diameter broadband ultrasound transducers with silicon pads. During measurement, the system initializes itself by having the two transducer pads touch momentarily. After applying the specific (oil-based) gel, the subject's heel was positioned on the foot support plate and strapped in place to restrain it from moving. The two transducers were electronically positioned on either side of the approximate midpoint of the calcaneus with a constant pressure maintaining direct contact with the patient's skin. For the fracture group, the measurements were performed at the heel of the nonfractured foot. BUA and speed of sound (SOS) were obtained from both systems. The Sahara combines BUA and SOS value linearly, with equal weighting, into a single parameter called the quantitative ultrasound index (QUI). QUI has a young adult value of about 100. This is analogous to the Stiffness parameter used by the Achilles system (Lunar, Madison, WI). Daily quality control (QC) was performed for both ultrasound systems with acoustic phantoms provided by the manufacturers. The short-term precision was performed twice with repositioning during a measurement session. The mid-term precision was obtained from 10 healthy young male and female volunteers measured twice per week for 2 months.

Dual X-ray Absorptiometric Measurements

Bone mineral measurements with DXA were performed with a bone densitometer (Hologic QDR-4500 scanner; Hologic, Waltham, MA) at the proximal femur on the same side as the QUS measurements. We measured total, neck and trochanter femoral BMD for each subject on the same day. BMD (g/cm^2) was calculated by dividing the amount of bone mineral content by the projected area

of the region of interest (ROI). Quality assurance phantom scans were performed to check system calibration on a daily basis.

Statistical Analysis

The results of all parameters were expressed as mean and standard deviation (SD). We assessed the in vivo short-term reproducibility in all subjects. The short-term precision (CV_S) or individual precision expressed as coefficient of variation for all subjects was given by the formula and averaged [18,19]:

$$CV_S = \frac{\sqrt{\sum_{j=1}^{M}\sum_{i=1}^{N_j}\frac{(X_{ij}-\overline{X}_j)^2}{N_j-1}}}{\sum_{j=1}^{M}\overline{X}_j}$$

where N_j is the number of measurements performed, X_{ij} is the result of the ith measurement for subject j, and $\overline{X}_j$ is the mean of all X_{ij} for subject j.

Standardized short term coefficient of variation (SCV) was calculated to compare the reproducibility of different parameters (BUA, SOS and QUI). It was calculated by the following equation [20,21]:

$$SCV = \frac{CVs\%}{4SD/mean}$$

where SD is the range of variation and mean is the average for all subjects.

For mid-term precision error, the standard error of the estimate (SEE) was taken as the estimate of the mid-term precision error rather than the standard deviation. The average of the technical mid-term precision error was defined by the random variation of repeated measurements on the same subject over time. It was expressed as the coefficient of variation (CV_M) by dividing the root mean square average SEE by the mean for all subjects and expressing the result as a percentage [18,22]. SEE results were estimated from the regression model:

$$CV_M = \frac{\sqrt{\overline{(SEE)^2}}}{\bar{x}}$$

We used bootstrap analysis to calculate the significant difference between the Sahara and UBA 575+ in standardized CV. All QUS and DXA measurements for the fracture and nonfracture group were compared using Student's *t*-test. Linear regression analysis was used to examine the correlation coefficients between QUS and DXA while the hypothesis test was used to calculate the regression coefficient. In addition, the correlation of BUA and SOS between the two devices was analyzed. Simple linear regression parameters were also determined by both ultrasound parameters and BMD, including the regression coefficient (β) and SEE for the linear regression equation. The diagnostic efficiency of the ultrasound parameters and BMD for fracture risk were estimated by the logistic regression model. From these models the odds ratio (OR) and 95% confidence intervals (95% CI) were estimated. To quantify the diagnostic ability of each method for hip fractures, the area under the receiver operating characteristic (ROC) curves for BMD and all QUS values was compared. All biostatistical analyses were completed with JMP, Microsoft Excel, S-plus and Labroc1 Clabroc software.

Results

Table 1 shows the short-term and mid-term precision errors of the two QUS systems. They are reported as coefficient of variation and standardized CV in percentages to estimate the QUS systems' reproducibility. We found a significant difference in standardized CV for BUA between the Sahara and the UBA 575+ ($p<0.05$). Comparing the standardized CV for SOS between the two devices, we did not find a difference when $\alpha = 0.05$; however, the Sahara's SOS was still significantly better than UBA 575+'s SOS when α was increased to 0.01. We correlated the first measurement and the repeat measurement and found excellent agreement (r value from 0.94 to 0.99). The mean difference between the two measurements was not significant, with a p value from 0.60 to 0.95 using a paired t-test.

The correlation between DXA and QUS was calculated for the pooled group using Pearson's correlation. The regression coefficient (β), SEE, correlation coefficient (r) and p value are reported in Table 2. There was moderate agreement between hip BMD and calcaneal QUS, with r ranging from 0.28 to 0.44. When we examined the regression coefficient with the t-test, the p value was less than 0.01 in all comparisons except for the Sahara SOS versus total hip and femoral neck BMD ($p<0.05$). Both ultrasound attenuation and velocity measured by the Sahara were highly correlated with the UBA 575+ values, with the correlation coefficient equal

Table 1. Reproducibility of all ultrasound variables for the Sahara and UBA 575+

		Sahara	UBA 575+
CV_S (%)	BUA	3.64	4.92
	SOS	0.27	0.61
	QUI	2.62	–
CV_M (%)	BUA	4.54	6.53
	SOS	0.51	0.20
	QUI	3.55	–
SCV (%)	BUA[a]	4.53	6.40
	SOS[b]	4.12	6.10
	QUI	3.42	–

CV_S, short-term coefficient of variation; CV_M mid-term coefficient of variation; SCV, standardized short term coefficient of variation.
[a] Significant difference between the Sahara and the UBA 575+ ($p<0.05$).
[b] No significant difference between the Sahara and the UBA 575+ ($p>0.05$).

Table 2. Pearson's correlation between hip BMD and ultrasound parameters

	$\beta \pm$ SEE	r	p
Total BMD			
BUA – Sahara	0.003 ± 0.0009 (g MHz/cm^2 dB)	0.41	<0.001
SOS – Sahara	0.001 ± 0.0005 (g s/cm^2 m)	0.30	<0.05
QUI – Sahara	0.002 ± 0.0008 (g/cm^2)	0.34	<0.005
BUA – UBA 575+	0.003 ± 0.0009 (g MHz/cm^2 dB)	0.38	<0.005
SOS – UBA 575+	0.008 ± 0.0019 (g s/cm^2 m)	0.36	<0.005
Neck BMD			
BUA – Sahara	0.003 ± 0.0008 (g MHz/cm^2 dB)	0.41	<0.001
SOS – Sahara	0.001 ± 0.0004 (g s/cm^2 m)	0.28	<0.05
QUI – Sahara	0.002 ± 0.0007 (g/cm^2)	0.33	<0.01
BUA – UBA 575+	0.002 ± 0.0008 (g MHz/cm^2 dB)	0.35	<0.01
SOS – UBA 575+	0.007 ± 0.0015 (g s/cm^2 m)	0.37	<0.005
Trochanter BMD			
BUA – Sahara	0.003 ± 0.0007 (g MHz/cm^2 dB)	0.44	<0.001
SOS – Sahara	0.001 ± 0.0004 (g s/cm^2 m)	0.37	<0.01
QUI – Sahara	0.002 ± 0.0006 (g/cm^2)	0.25	<0.001
BUA – UBA 575+	0.003 ± 0.0007 (g MHz/cm^2 dB)	0.42	<0.001
SOS – UBA 575+	0.007 ± 0.0014 (g s/cm^2 m)	0.44	<0.001
BUA – Sahara/BUA – UBA 575+	1.004 ± 0.0562	0.92	<0.0001
SOS – Sahara/SOS – UBA 575+	0.212 ± 0.0163	0.91	<0.0001

β, regression coefficient; SEE, standard error of estimate.

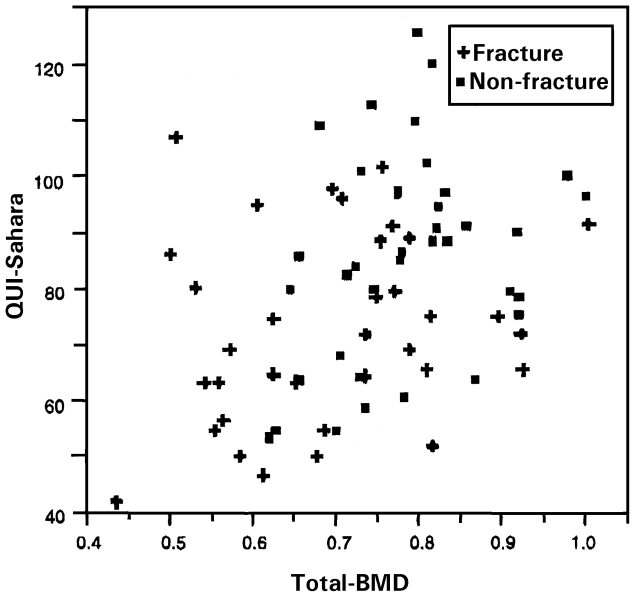

Fig. 1. Scatter plot of total femoral BMD and Sahara QUI in fracture and nonfracture subjects.

to 0.91 for BUA and 0.92 for SOS. Figure 1 is a scatter plot of the total femoral BMD and Sahara QUI values in fracture and nonfracture subjects.

Table 3 provides general anthropometric, BMD and QUS variables for the fracture and nonfracture groups. Among the 68 subjects there were no significant differences (p value from 0.4805 to 0.9415) between the fracture and nonfracture groups for the mean of age, height, weight and BMI values. The t values ranged from 0.074 to 4.053. Both QUS and DXA measurements were significantly higher in the control group ($p<0.005$).

To determine the ability of the ultrasound measurement to discriminate between the hip fracture group and the normal group, we computed the odds ratio per standard deviation decrease in each parameter from the logistic regression coefficient and standard deviation. As shown in Table 3, there were no significant differences in general anthropometric variables between the fracture and the control group. Therefore, the odds ratio was not adjusted by age, weight, height or BMI. The odds ratios of ultrasound and BMD parameters are presented, together with the 95% confidence interval, in Table 4. To assess whether QUS is capable of discriminating hip fracture independently, we also adjusted the logistic regressions for total, neck and trochanter femoral BMD, respectively. Results are shown in Table 4.

ROC analysis was also used to evaluate the ability of QUS to discriminate women with osteoporotic fractures from normal subjects. The ROC curve of some bone parameters are displayed in Fig. 2, which plots patients with fracture and their healthy counterparts. The area under the ROC curve was 0.73 for total BMD, 0.75 for neck BMD, 0.74 for trochanter BMD, 0.77 for Sahara's BUA, 0.75 for Sahara's SOS, 0.77 for Sahara's QUI, 0.77 for UBA 575+'s BUA, and 0.78 for UBA 575+'s SOS, respectively. Our results demonstrated no significant differences by a two-tailed p value ($p>0.05$) between each calcaneal QUS measurement and femoral neck BMD.

Discussion

QUS measurements provided a better standardized coefficient of variation for BUA by using the Sahara than that by using the UBA 575+. And both QUS

Table 3. Comparison of anthropometric, QUS and DXA variables for the two groups

	Hip fracture (n = 33)	Controls (n = 35)	p^a	t^a
Age (years)	74.50 ± 8.1	75.70 ± 5.60	NS	0.705
Height (cm)	159.63 ± 7.36	159.50 ± 7.21	NS	0.074
Weight (kg)	62.47 ± 12.61	64.74 ± 14.33	NS	0.692
BMI (kg/m^2)	24.44 ± 4.29	25.41 ± 5.11	NS	0.839
Total hip BMD (g/cm^2)	0.69 ± 0.14	0.79 ± 0.09	<0.001	3.426
Trochanter BMD (g/cm^2)	0.53 ± 0.10	0.60 ± 0.08	<0.005	3.024
Neck BMD (g/cm^2)	0.57 ± 0.11	0.65 ± 0.08	<0.005	3.367
BUA – Sahara (dB/MHz)	50.13 ± 15.05	63.49 ± 13.34	<0.001	3.878
SOS – Sahara (m/s)	1515.82 ± 25.24	1541.30 ± 31.83	<0.001	3.643
QUI – Sahara	71.03 ± 16.17	86.96 ± 17.98	<0.001	3.834
BUA – UBA 575+ (dB/MHz)	57.39 ± 14.56	72.40 ± 15.50	<0.001	4.013
SOS – UBA 575+ (m/s)	1574.36 ± 51.05	1592.29 ± 53.29	<0.001	3.865

Values are the mean ± SD.
[a] Student's t-test.

Table 4. The ability of BMD and ultrasound variables to discriminate the risk of hip fracture

	Total BMD	Neck BMD	Trochanter BMD	BUA – Sahara	SOS – Sahara	QUI – Sahara	BUA – UBA 575+	SOS UBA 575+
OR	2.5**	2.5**	2.2**	2.7**	2.7**	2.8***	3.0***	3.2***
(95% CI)	(1.4–4.3)	(1.3–4.6)	(1.2–4.0)	(1.5–5.0)	(1.4–5.0)	(1.5–5.2)	(1.6–5.9)	(1.6–6.4)
Adjusted for total hip BMD								
OR	—	—	—	2.3*	2.3*	2.4**	2.5**	2.6**
(95% CI)				(1.2–4.3)	(1.2–4.4)	(1.2–4.5)	(1.3–5.0)	(1.3–5.4)
Adjusted for neck BMD								
OR	—	—	—	2.3*	2.4**	2.4**	2.6**	2.7**
(95% CI)				(1.2–4.3)	(1.2–4.5)	(1.3–4.5)	(1.3–5.1)	(1.3–5.8)
Adjusted for trochanter BMD								
OR	—	—	—	2.3**	2.2*	2.3**	2.5**	2.5*
(95% CI)				(1.2–4.3)	(1.2–4.3)	(1.2–4.4)	(1.3–5.0)	(1.2–5.2)

OR, odds ratio for a 1 SD decrease of the independent variable.
*p<0.05; **p<0.01; ***p<0.001.

systems showed comparable short-term and mid-term precision. The investigation indicated that the Sahara had a moderate correlation with hip BMD measurements. Generally, higher reproducibility was found in the Sahara than in the UBA 575+. The BUA index for the UBA 575+ appeared to have the same precision as reported by Bauer et al. [13], but was not higher than that of the Sahara. Our findings are consistent with other studies using the same equipment [23,24]. Compared with its predecessor, the UBA 575+, the Sahara showed higher precision. As expected, we found a strong correlation between the two devices (r = 0.91–0.92).

QUS measurements of bone have been used for many years to investigate the mechanical properties of various bone tissues. Reports have shown that QUS can provide information on bone density as well as on bone structure, which is undetectable by DXA [25–29]. A growing number of researchers have used QUS to assess bone status for prediction of osteoporotic fracture risk [30–32]. The Walker-Sonix series have been widely used in osteoporotic fracture studies and have shown a good ability to predict fracture risk [12,13,15,33,34]. The Walker-Sonix measured the calcaneus with the foot placed in a water tank and fixed by a stabilizer to minimize possible movement. The measurement kept the foot in water for 15 minutes, a considerable amount of time. Foot positioning may cause imperfect precision due to the high variation in calcaneal trabecular structure, particularly for measurements over a long period. The temperature of the water proved to be another problem [17]. The Sahara was designed to eliminate the need for a water bath, to provide easier positioning and to reduce measurement time. These advantages may help to improve reproducibility by means of easier repositioning and stable water temperature over the short measurement time. Additionally the Sahara contributes a new parameter, QUI, which combines BUA and SOS. The standardized coefficient of variation was defined to relate the precision of various parameters to different scales of physiologic variations. Our results indicate that QUI has an acceptable reproducibility as well as BUA and SOS (Table 1).

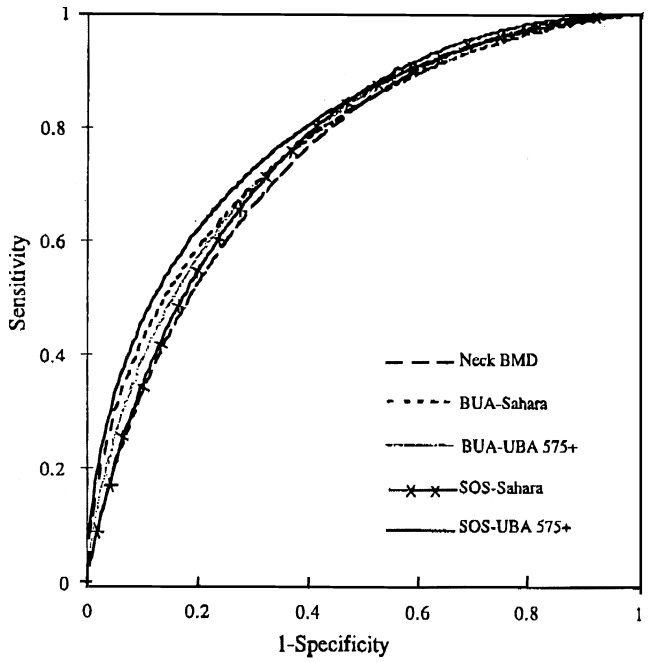

Fig. 2. ROC curves of femoral neck BMD and QUS measurements.

We investigated the relationship of all ultrasound parameters (BUA, SOS, QUI) with total, neck and trochanter BMD. For both QUS systems, SOS had better correlation compared with the trochanter than when compared with total and neck BMD (Table 2). Our correlations between hip BMD and calcaneal BUA appeared similar to that reported in other studies [15,35], which demonstrated a poor to moderate correlation with an *r* value around 0.3–0.5, but never higher than 0.6. as reported, the site-matched correlations between QUS and DXA were significantly higher (*r* from 0.66 to 0.86) [4,16]. However, the correlations between calcaneal QUS measurements and hip BMD in our study were relatively comparable to the correlations among different sites obtained by DXA [36].

In the present study, the Sahara system discriminated osteoporotic hip fracture risk as well as DXA and the UBA 575+. Cummings et al. [37] assessed bone density at several sites in 8134 women aged 65 years or more and found that low femoral neck bone density is a stronger predictor of hip fracture than BMD at other places. The reported odds ratios for hip fracture by BMD ranged between 1.2 and 2.5 per standard deviations of bone loss [7]. Other studies have shown that the information from ultrasound of the calcaneus is related to hip fractures [13,34,38,39]. Our results showed that the presence of hip fracture was significantly related to QUS, with similar odds ratios ranging from 2.7 to 3.2. Thus, the lower QUS parameters at the calcaneus were important indicators of increasing risk of hip fracture. Even after adjusting the logistic regressions for total, neck and trochanter BMD, QUS variables still discriminated hip fracture significantly. In addition, the new QUS value of the Sahara, QUI, showed a comparable odds ratio with other Sahara parameters as well (Table 4).

Our data demonstrate that measurements at the calcaneus using the Sahara can distinguish subjects with hip fracture from those without. All QUS and BMD measurements presented significantly lower values in the fracture group than in the nonfracture group. The area under the ROC curve was not significantly different between calcaneal QUS and femoral neck BMD ($p>0.05$). Using DXA BMD of the hip as a diagnostic standard, all the Sahara's parameters have a sensitivity and specificity similar to BMD, which is consistent with other reports [13,16,38]. Most cross-sectional and prospective studies by ultrasound have revealed a significant difference between healthy women and women with hip fracture [33,34,38,40,41]. Along with BMD measurements, ultrasound consistently remained an alternative for discriminating subjects with hip fractures from control. Data from the present study show that propensity to hip fracture related to lower bone density is reflected in calcaneal ultrasound measurement.

In conclusion, our investigation indicates that the Sahara Bone Sonometer device can discriminate hip fracture risk equally as well as DXA. With its water-free technique, less complex handling and better precision, the Sahara outperforms the UBA 575+ for the study of osteoporotic populations. In our study, however, the possible sources of precision errors such as foot positioning and foot temperature were not investigated. Further studies are required for a more comprehensive assessment of the prediction of fracture risk at other skeletal sites by using Sahara calcaneus measurement, and in increased sample size will be considered to improve the limitation of this study.

References

1. Melton LJ III. How many women have osteoporosis? J Bone Miner Res 1995;10:175–7.
2. Kelsey J, Hoffman S. Risk factors for hip fracture. N Engl J Med 1987;316:404–5.
3. Melton LJ III, Thamer M, Ray N, Chan J, Chesnut CR. Fractures attributable to osteoporosis: report from the National Osteoporosis Foundation. J Bone Miner Res 1997;12:16–23.
3. Waud CE, Lew R, Baran DT. The relationship between ultrasound and densitometric measurements of bone mass at the calcaneus in women. Calcif Tissue Int 1992;51:415–8.
5. Goldstein S, Goulet R, McCubbrey D. Measurement and significance of three-dimensional architecture in the mechanical integrity of trabecular bone. Calcif Tissue Int 1993;53:S127–133.
6. Recker R. Architecture and vertebral fracture. Calcif Tissue Int 1993;53:S139–42.
7. Ott S. When bone mass fails to predict bone failure. Calcif Tissue Int 1993;53:S7–13.
8. Hans D, Fuerst T, Duboeuf F. Quantitative ultrasound bone measurement. Eur Radiol 1997;7(Suppl 2):S43–50.
9. Hans D, Schott AM, Meunier PJ. Ultrasonic assessment of bone: a review. Eur J Med 1993;2:157–63.
10. Hans D, Arlot ME, Schott AM, Roux JP, Kotzki PO, Meunier PJ.

Do ultrasound measurements on the os calcis reflect more the bone microarchitecture than the bone mass? A two-dimensional histomorphometric study. Bone 1995;16:295–300.
11. Njeh CF, Boivin CM, Langton CM. The role of ultrsound in the assessment of osteoporosis: a review. Osteoporos Int 1997;7:7–22.
12. Glüer C, Bauer D, Uffmann M, Heitz M, Liffschutz R, Cummings S, Genant H. Searching for new and improved quantitative ultrasound parameters: the Study of Osteoporotic Fractures. J Bone Miner Res 1996;11:S119.
13. Bauer DC, Glüer CC, Cauley JA, Vogt TM, Ensrud KE, Genant HK, Black DM. Broadband ultrasound attenuation predicts fractures strongly and independently of densitometry in older women: a prospective study. Study of Osteoporotic Fractures Research Group. Arch Intern Med 1997;157:629–34.
14. Baran DT, Kelly AM, Karellas A, Gionet M, Price M, Leahey D, et al. Ultrasound attenuation of the os calcis in women with osteoporosis and hip fractures. Calcif Tissue Int 1988;43:138–42.
15. Funke M, Kopka L, Vosshenrich R, Fischer U, Ueberschaer A, Oestmann JW, et al. Broadband ultrasound attenuation in the diagnosis of osteoporosis: correlation with osteodensitometry and fracture. Radiology 1995;194:77–81.
16. Greenspan S, Bouxsein M, Melton M, Kolodny A, Clair J, Delucca P, et al. Precision and discriminatory ability of calcaneal bone assessment technologies. J Bone Miner Res 1997;12:1303–13.
17. Evans WD, Jones EA, Owen GM. Factors affecting the in vivo precision of broad-band ultrasonic attenuation. Phys Med Biol 1995;40:137–51.
18. Glüer CC, Blake G, Lu Y, Blunt BA, Jergas M, Genant HK. Accurate assessment of precision errors: how to measure the reproducibility of bone densitometry techniques. Osteoporos Int 1995;5:262–70.
19. Ravn P, Overgaard K, Huang C, Ross P, Green D, McClung M. Comparison of bone densitomtery of the phalanges, distal forearm and axial skeleton in early postmenopausal women participating in the EPIC study. Osteoporos Int 1996;6:308–13.
20. Fournier B, Chappard C, Roux C, Berger G, Laugier P. Quantitative ultrasound imaging at the calcaneus using an automatic region of interest. Osteoporos Int 1997;7:363–9.
21. Orgee JM, Foster H, McCloskey EV, Khan S, Coombes G, Kanis JA. A precise method for the assessment of tibial ultrasound velocity. Osteoporos Int 1996;6:1–7.
22. Blake G, Fogelman I. Technical principles of dual energy x-ray absorptiometry. Semini Nucl Med 1997;27:210–28.
23. Alenfeld F, Diessel E, Schmidt D, Felsenberg D. Comparison of reference values of two calcaneal ultrasound systems: the Sahara Bone Sonometer and the Achilles Plus. J Bone Miner Res 1997;12:S387.
24. Moris M, Peretz A, Tjeka R, Negaban N, Wouters M, Bergmann P. Quantitative ultrasound bone measurments: normal values and comparison with bone mineral density by dual-energy X-ray absorptiometry. Calcif Tissue Int 1995;57:6–10.
25. Heaney R. Osteoporotic fracture space: an hypothesis. Bone Miner 1989;6:1–13.
26. Glüer CC, Wu CY, Jergas M, Goldstein SA, Genant HK. Three quantitative ultrasound parameters reflect bone structure. Calcif Tissue Int 1994;55:46–52.
27. Glüer CC, Wu CY, Genant HK. Broadband ultrasound attenuation signals depend on trabecular orientation: asin vitro study. Osteoporos Int 1993;3:185–91.
28. Turner CH, Eich M. Ultrasonic velocity as a predictor of strength in bovine cancellous bone. Calcif Tissue Int 1991;49:116–9.
29. Bouxsein ML, Courtney AC, Hayes WC. Ultrasound and densitometry of the calcaneus correlate with the failure loads of cadaveric femurs. Calcif Tissue Int 1995;56:99–103.
30. Kaufman JJ, Einhorn TA. Ultrasound assessment of bone. J Bone Miner Res 1993;8:517–25.
31. Brandenburger GH. Clinical determination of bone quality: is ultrasound an answer? Calcif Tissue Int 1993;53(Suppl 1):S151–6.
32. Faulkner K, McClung M, Coleman L, Kingston-Sadahl E. Quantitative ultrasound of the heel: correlation with densitometric measurements at different skeletal sites. Osteoporos Int 1994;4:42–7.
33. Porter RW, Miller CG, Grainger D, Palmer SB. Prediction of hip fracture in elderly women: a prospective study. BMJ 1990;301:638–41.
34. Mautalen C, Vega E, Gonzalez D, Carrilero P, Otano A, Silberman F. Ultrasound and dual X-ray absorptiometry densitometry in women with hip fracture. Calcif Tissue Int 1995;57:165–8.
35. Massie A, Reid DM, Porter RW. Screening for osteoporosis: comparison between dual energy X-ray absorptiometry and broadband ultrasound attenuation in 1000 perimenopausal women. Osteoporos Int 1993;3:107–10.
36. Kleerekoper M, Nelson D, Flynn M, Pawluszka A, Jacobsen G, Peterson E. Comparison of radiographic absorptiometry with dual-energy X-ray absorptiometry and quantitative computed tomography in normal older white and black women. J Bone Miner Res 1994;9:1745–9.
37. Cummings SR, Black DM, Nevitt MC, Browner W, Cauley J, Ensrud K, et al. Bone density at various sites for prediction of hip fractures. The Study of Osteoporotic Fractures Research Group. Lancet 1993;341:72–5.
38. Schott AM, Weill-Engerer S, Hans D, Duboeuf F, Delmas PD, Meunier PJ. Ultrasound discriminates patients with hip fracture equally well as dual energy X-ray absorptiometry and independently of bone mineral density. J Bone Miner Res 1995;10:243–9.
39. Han S, Rho J, Medige J, Ziv I. Ultrasound velocity and broadband attenuation over a wide range of bone mineral density. Osteoporos Int 1996;6:291–6.
40. Funck C, Wüster C, Alenfeld F, Pereira-Lima JFS, Fritz T, Meeder PJ, et al. Ultrasound velocity of the tibia in normal German women and hip fracture patients. Calcif Tissue Int 1996;58:390–4.
41. Hans D, Dargent-Molina P, Schott AM, Sebert JL, Cormier C, Kotzki PO, et al. Ultrasonographic heel measurements to predict hip fracture in elderly women: the EPIDOS prospective study. Lancet 1996;348:511–4.

Received for publication 29 October 1998
Accepted in revised form 7 September 1999