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Ultrasonic Measurement of the Calcaneus in Polish Normal and Osteoporotic Women and Men

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In this cross-sectional study, 964 subjects (740 postmenopausal women and 224 men) who underwent ultrasound measurement of the calcaneus at the outpatient osteoporotic clinic in the years 1993–1996 were evaluated. The aim of the study was to compare the influence of age, years since menopause (YSM), and body size on ultrasound variables in normal and osteoporotic male and female populations as well as to assess the ability of quantitative ultrasound (qUS) to discriminate between healthy and osteoporotic individuals. The subjects were divided into four age-matched groups: normal women (n = 601, mean age 56.3 ± 4.8 years); osteoporotic women (n = 139, mean age 56.5 ± 4.8 years); normal men (n = 148, mean age 56.2 ± 10.2 years); and osteoporotic men (n = 76, mean age 56.5 ± 10.7 years). Persons with a history of a disease and/or medications known to affect bone metabolism were excluded. Broadband ultrasound attenuation (BUA, in decibels per megahertz) and speed of sound (SOS, in meters per second) were measured using Achilles device (Lunar, Madison, WI). Short- and long-term in vitro coefficients of variation (CVs) were: 1.23% and 0.54% for BUA and 0.12% and 0.14% for SOS, respectively. Short-term in vivo CVs were: in women, BUA 1.8% and SOS 0.22%; and, in men, 2.48% and 0.33%, respectively. SOS and BUA values were significantly higher in healthy men (1517.5 ± 35.3 m/sec, 114.0 ± 13.3 dB/MHz) than in healthy women (1511.1 ± 25.6 m/sec, 108.7 ± 9.5 dB/MHz) ($p < 0.000001$). The two ultrasound variables had higher values in osteoporotic men (SOS = 1492.6 ± 24.6 m/sec, BUA = 106.1 ± 11.6 dB/MHz) in comparison to osteoporotic women (SOS = 1490.4 ± 19.5 m/sec, BUA = 103.2 ± 8.6 dB/MHz), but the differences did not achieve significance. In both genders, ultrasound parameters were significantly lower in osteoporotic groups ($p < 0.000001$). The following age-adjusted odds ratios were obtained: in women, 1.7 (95% CI 1.42–2.03) for BUA, and 2.3 (95% CI 1.87–2.81) for SOS; in men, 1.05 (95% CI 0.03–2.07) for BUA, and 2.13 (95% CI 0.77–3.49) for SOS. ROC analyses performed in both genders showed the following area under the curve data: in women, 0.66 for BUA, and 0.74 for SOS; and, in men, 0.66 for BUA, and 0.71 for SOS. Multiple regression analysis showed age to be the main negative determinant of both ultrasound variables in healthy women, and YSM in osteoporotic women. In both genders, weight was found to have a positive influence on SOS and BUA values, whereas the effect of height was weaker and generally negative. It can be concluded that ultrasound measurement at the calcaneus is able to discriminate between normal male/female and osteoporotic male/female populations in a similar manner. Women had greater rates of decrease in BUA and SOS with age compared with rates in men, and the decrease was greater in normal individuals in both genders. Distinct gender-related differences were noted in regard to correlations of ultrasound parameters with body size. (Bone 24:611–617; 1999) **© 1999 by Elsevier Science Inc. All rights reserved.**

Key Words: Calcaneus; Women; Men; Normal; Osteoporotic; Quantitative ultrasound.

Introduction

Ultrasound measurement of the skeleton, especially at the calcaneus, is growing in popularity. The choice of the calcaneus as a measurement site is validated by the fact that this bone is greater than 90% trabecular by volume.[20] Cancellous bone, due to its high turnover rate, shows changes within bone tissue earlier than in compact bone. In several studies based on ultrasound calcaneal measurements normative values for women were established.[4,6,8,9,13,18,20] Many studies concerning the relationship of ultrasonic parameters with age, years since menopause (YSM), and body size have been done in female populations.[4,6,7–9,12,13,20,22] In some studies, quantitative ultrasound (qUS) in both women and men was evaluated,[4,6,8,16] but the male populations studied were relatively small (42, 100, 169, or 300 men). Some correlations between age and ultrasound parameters in male populations were noted. Several studies have shown that calcaneal ultrasound measurement can discriminate between osteoporotic and normal women.[2,5,7,12,19] Moris et al.[8] demonstrated the ability of qUS to discriminate between healthy men and men with foot algodystrophy.

The aim of the present study was to obtain ultrasound measurements from a large sample of normal and osteoporotic women and men. We compared general trends in both genders (influence of age, YSM, and body size on ultrasound variables) and the ability of qUS to discriminate between healthy and osteoporotic individuals.

Materials and Methods

Materials

In the study, 740 postmenopausal women (601 normals, age range 45–65 years; 139 osteoporotics, age range 44–63 years)

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Table 1. Clinical characteristics of the subjects studied

	All women (n = 740)	All men (n = 224)	*p* value
Age (years)	56.3 ± 4.8	56.3 ± 10.3	n.s.
Weight (kg)	67.5 ± 9.9	78.9 ± 11.8	<0.001
Height (m)	1.59 ± 0.05	1.72 ± 0.07	<0.001
BMI (kg/m^2)	26.7 ± 3.6	26.6 ± 3.4	n.s.
YSM (years)	7.4 ± 5.2	—	—

KEY: BMI, body mass index; n.s., not significant; YSM, years since menopause.

Table 2. Clinical characteristics of the groups studied

	Group 1: normal women (n = 601)	Group 2: osteoporotic women (n = 139)	Group 3: normal men (n = 148)	Group 4: osteoporotic men (n = 76)
Age[a] (years)	56.3 ± 4.8	56.4 ± 4.7	56.2 ± 10.2	56.5 ± 10.6
Weight[b] (kg)	67.8 ± 10.1	66.3 ± 8.8	79.7 ± 11.4	77.2 ± 12.5
Height[c] (m)	1.59 ± 0.05	1.58 ± 0.05	1.72 ± 0.07	1.71 ± 0.08
BMI[d] (kg/m^2)	26.8 ± 3.7	26.4 ± 3.3	26.7 ± 3.4	26.4 ± 3.5
YSM[e] (years)	7.3 ± 5.1	8.3 ± 5.3	—	—

See Table 1 for abbreviations.
[a]Significance of differences for: group 1 vs. 2, n.s.; group 3 vs. 4, n.s.; group 1 vs. 3, n.s.; group 2 vs. 4, n.s.
[b]Significance of differences for: group 1 vs. 2, n.s.; group 3 vs. 4, n.s.; group 1 vs. 3, $p < 0.05$; group 2 vs. 4, $p < 0.05$.
[c]Significance of differences for: group 1 vs. 2, n.s.; group 3 vs. 4, $p < 0.05$; group 1 vs. 3, $p < 0.05$; group 2 vs. 4, $p < 0.05$.
[d]No significant differences between groups (i.e., all n.s.).
[e]Significance of difference between group 1 and 2, $p = 0.042$.

and 224 men (148 normals, age range 36–79 years; 76 osteoporotics, age range 36–86 years) were evaluated. The subjects were selected from 2852 women and 255 men who underwent qUS measurement at the calcaneus at the outpatient osteoporotic clinic in the years 1993–1996. The four groups studied were matched for age. Clinical characteristics are presented in **Tables 1 and 2.** No conditions affecting bone metabolism (diseases or medications) were noted. The data were gathered on the basis of a medical interview conducted by the same physician. At the time of measurement none of the subjects was treated for osteoporosis. Because of the retrospective design of our study we were not able to evaluate properly the physical activity, smoking, alcohol, and caffeine intake, and these data are not included. All fractures were the result of minimal trauma (men [n = 120]: 23 spine, 4 hip, 19 wrist, 2 humerus, 21 ankle, 23 foot, 11 clavicle, 17 rib; women [n = 216]: 22 spine, 115 wrist, 7 humerus, 14 ankle, 39 foot, 4 clavicle, 15 rib). Informed consent was obtained from all the subjects, and the study was approved by the local ethics committee.

Methods

Evaluation of the skeletal status was based on ultrasound measurements of the calcaneus at the right (dominant) heel. In the case of a previous fracture within the lower extremity the opposite calcaneus was measured. The speed of sound (SOS; in meters per second) and broadband ultrasound attenuation (BUA; in decibels per megahertz) were measured with the Achilles system (Lunar, Madison, WI), which was calibrated daily in accordance with the manufacturer's recommendations. All measurements were done by the same operator. Reproducibility was assessed using a polyurethane phantom on the basis of in vivo measurements. Fifteen phantom measurements in 15 days allowed calculation of short-term in vitro coefficients of variation (CVs): SOS, 0.12%; BUA, 1.23%. Long-term in vitro CVs obtained on the basis of 22 measurements of the phantom during 3 months were SOS 0.14% for and 0.54% for BUA. Short-term in vivo precision in women was established on the basis of 100 measurements in 20 healthy women (5 for each of them). The CVs were 1.8% for BUA and 0.22% for SOS. In men, short-term in vivo precision was calculated on the basis of 60 measurements in 12 healthy men (5 for each of them) and CVs were 2.48% for BUA and 0.33% for SOS.

Statistics

Calculations of means and standard deviations as well as linear and multiple regression analyses were performed using the STATISTICA program run on an IBM computer. Differences between mean values were established using Student's *t*-test. The age-adjusted odds ratio was calculated using logistic regression (SPSS software). Receiver-operating characteristic (ROC) analyses were performed using LABROC software. Fisher's exact test was used for comparison between coefficients of correlation.

Results

Mean ultrasound values for the groups studied are shown in **Table 3.** SOS and BUA values were significantly higher in healthy men than in healthy women ($p < 0.000001$). **Figures 1, 2, 3, and 4** show BUA and SOS values separately for spine and peripheral fracture in both genders. Both ultrasound variables had higher values in osteoporotic men in comparison to osteoporotic women, but the differences were not statistically significant. In both genders, the ultrasound values were significantly lower in osteoporotic individuals ($p < 0.000001$). The following age-adjusted odds ratios were obtained: BUA 1.7 (95% CI 1.42–2.03), and SOS 2.3 (95% CI 1.87–2.81) for women; and BUA 1.05 (95% CI 0.03–2.07), and SOS 2.13 (95% CI 0.77–3.49) for men. ROC analyses performed in both genders showed the following areas under the curve: BUA 0.66 and SOS 0.74 for women; and BUA 0.66 and SOS 0.71 for men. ROC curves are

Table 3. Ultrasound values in groups studied

	Group 1: normal women (n = 601)	Group 2: osteoporotic women (n = 139)	Group 3: normal men (n = 148)	Group 4: osteoporotic men (n = 76)
SOS[a] (m/s)	1511.1 ± 25.6	1490.4 ± 19.5	1517.5 ± 35.3	1492.6 ± 24.6
BUA (dB/MHz)	108.7 ± 9.5	103.2 ± 8.6	114.0 ± 13.3	106.1 ± 11.6

KEY: BUA, broadband ultrasound attenuation; SOS, speed of sound.
[a]Significance of differences for: group 1 vs. 2, $p < 0.000001$; group 3 vs. 4, $p < 0.000001$; group 1 vs. 3, $p < 0.01$; group 2 vs. 4, n.s.
[b]Significance of differences for: group 1 vs. 2, $p < 0.000001$; group 3 vs. 4, $p < 0.000001$; group 1 vs. 3, $p < 0.000001$; group 2 vs. 4, n.s.

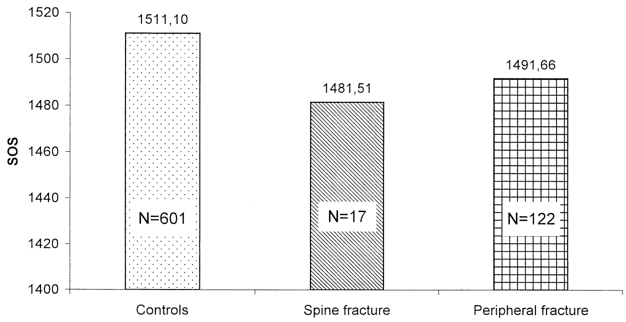

Figure 1. SOS values in female controls and in cases with spine and peripheral fractures.

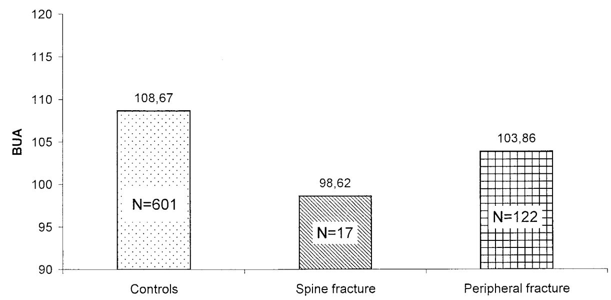

Figure 2. BUA values in female controls and in cases with spine and peripheral fractures.

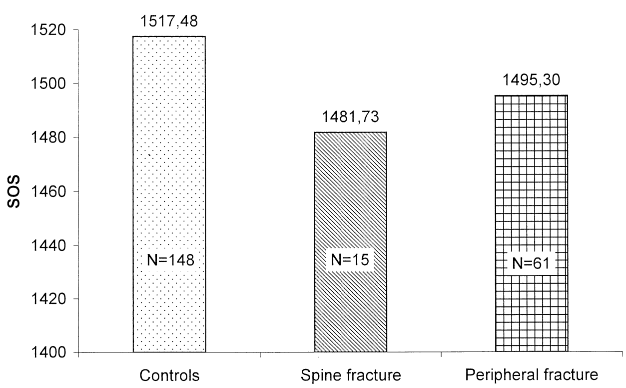

Figure 3. SOS values in male controls and in cases with spine and peripheral fractures.

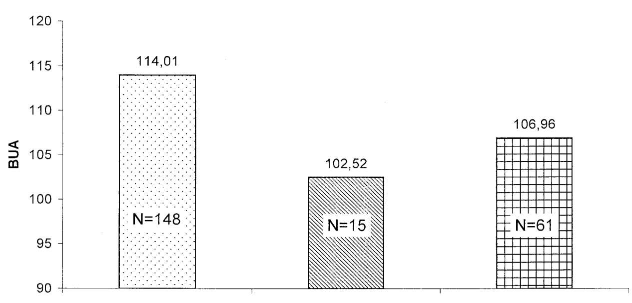

Figure 4. BUA values in male controls and in cases with spine and peripheral fractures.

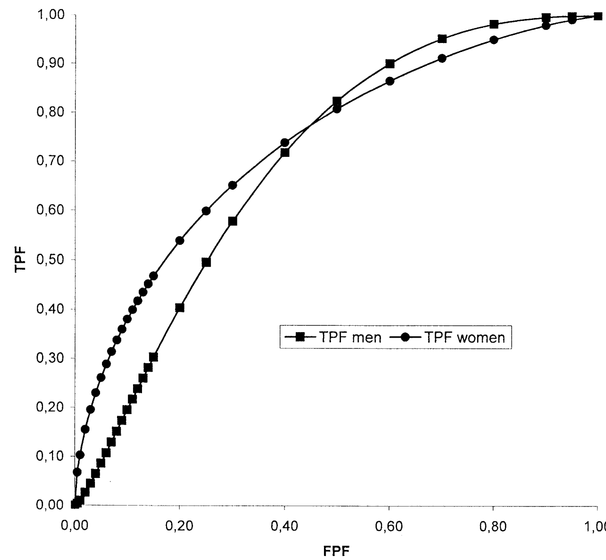

Figure 5. ROC curve for SOS.

shown in **Figures 5 and 6.** The simple linear regression of ultrasound variables and age, YSM, and body size are shown in **Table 4.** In healthy women, SOS and BUA decreased significantly with age ($p < 0.000001$) and YSM ($p < 0.001$), and significant correlations with body size (height, weight, BMI) were found for both ultrasound values, except for the correlation of SOS with height. In osteoporotic women, we found a significant age-related decrease in BUA only ($p < 0.01$). SOS correlated positively with weight only ($p < 0.05$), whereas BUA showed a significant correlation with weight ($p < 0.001$), height ($p < 0.05$), and BMI ($p < 0.001$). In healthy men, only SOS decreased significantly with age ($p < 0.05$) and no correlations between ultrasound variables and body size were noted. In osteoporotic men no significant correlations of SOS and BUA with age were observed. The only significant correlation was

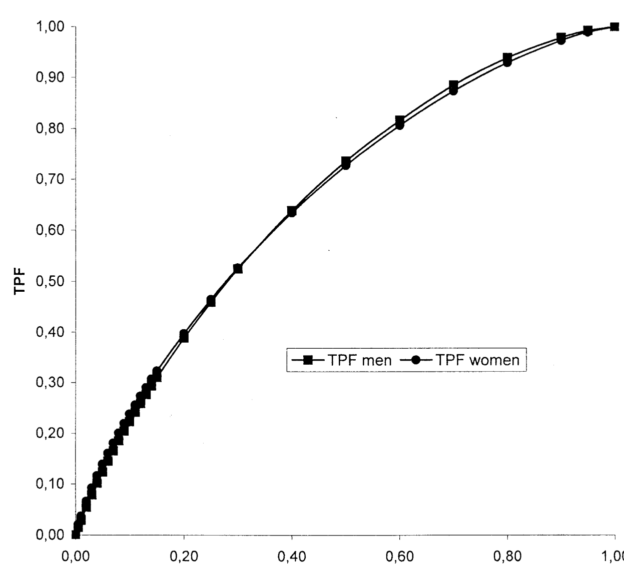

Figure 6. ROC curve for BUA.

Table 4. The correlations and regressions of ultrasound values with age, years since menopause, and body size

Linear regression equation	r	p value
Group 1		
SOS = 1614.3 − 1.83 × age	−0.34	<0.000001
SOS = 1522.1 − 1.51 × YSM	−0.30	<0.000001
SOS = 1490.1 + 0.31 × weight	0.12	<0.01
SOS = 1451.4 + 0.38 × height	0.08	n.s.
SOS = 1494.0 + 0.64 × BMI	0.09	<0.05
BUA = 142.8 − 0.60 × age	−0.30	<0.000001
BUA = 112.2 − 0.49 × YSM	−0.26	<0.000001
BUA = 90.4 + 0.27 × weight	0.29	<0.000001
BUA = 51.8 + 0.36 × height	0.20	<0.00001
BUA = 94.5 + 0.53 × BMI	0.21	<0.000001
Group 2		
SOS = 1527.0 − 0.65 × age	−0.16	n.s.
SOS = 1499.5 − 1.08 × YSM	−0.29	<0.001
SOS = 1460.5 + 0.45 × weight	0.20	<0.05
SOS = 1443.6 + 0.29 × height	0.08	n.s.
SOS = 1465.0 + 0.96 × BMI	0.16	n.s.
BUA = 129.6 − 0.47 × age	−0.26	<0.01
BUA = 108.1 − 0.59 × YSM	−0.36	<0.0001
BUA = 82.7 + 0.31 × weight	0.32	<0.001
BUA = 61.0 + 0.27 × height	0.17	<0.05
BUA = 86.6 + 0.63 × BMI	0.24	<0.01
Group 3		
SOS = 1551.4 − 0.60 × age	−0.17	<0.05
SOS = 1514.0 + 0.04 × weight	0.01	n.s.
SOS = 1532.7 − 0.08 × height	−0.02	n.s.
SOS = 1510.5 + 0.26 × BMI	0.02	n.s.
BUA = 124.0 − 0.18 × age	−0.14	n.s.
BUA = 103.3 + 0.13 × weight	0.12	n.s.
BUA = 108.1 + 0.03 × height	0.02	n.s.
BUA = 100.9 + 0.49 × BMI	0.12	n.s.
Group 4		
SOS = 1505.7 − 0.23 × age	−0.10	n.s.
SOS = 1469.8 + 0.30 × weight	0.15	n.s.
SOS = 1495.1 − 0.01 × height	−0.004	n.s.
SOS = 1453.8 + 1.47 × BMI	0.21	n.s.
BUA = 104.9 + 0.02 × age	0.02	n.s.
BUA = 84.3 + 0.28 × weight	0.31	<0.01
BUA = 72.4 + 0.19 × height	0.13	n.s.
BUA = 79.0 + 1.03 × BMI	0.31	<0.01

KEY: BMI, body mass index; BUA, broadband ultrasound attenuation; n.s., not significant; SOS, speed of sound; YSM, years since menopause.

obtained between BUA and weight and BMI ($p < 0.01$). In **Figures 7, 8, 9, 10, 11, 12, 13,** and **14,** the age-related changes in ultrasound parameters are shown.

Multiple regression analyses of ultrasound variables and age, YSM, and body size are shown in **Table 5.** In healthy women, the main, negative determinant of the two ultrasound variables was age with a positive influence of weight and a weaker, generally negative influence of height. In fractured women, a stronger, negative determinant was YSM, and weight and height showed a varying influence on SOS and BUA.

Coefficients of correlation obtained in simple linear regression between ultrasound values and age were compared using Fisher's exact test. The coefficients were significantly different: in healthy groups between age and both ultrasound variables; in osteoporotic groups between age and BUA only; and in female groups between age and SOS only.

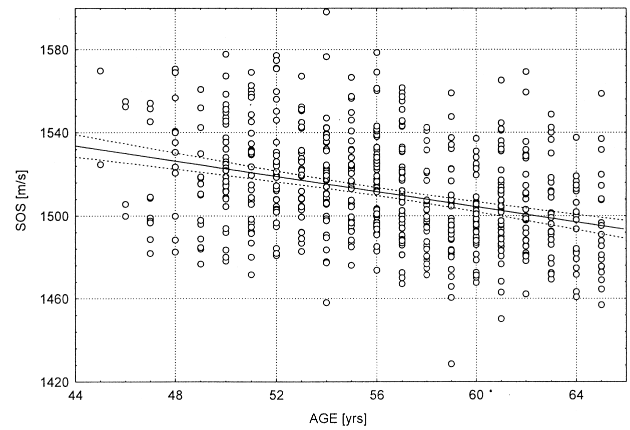

Figure 7. Simple linear regression between age and SOS in healthy women.

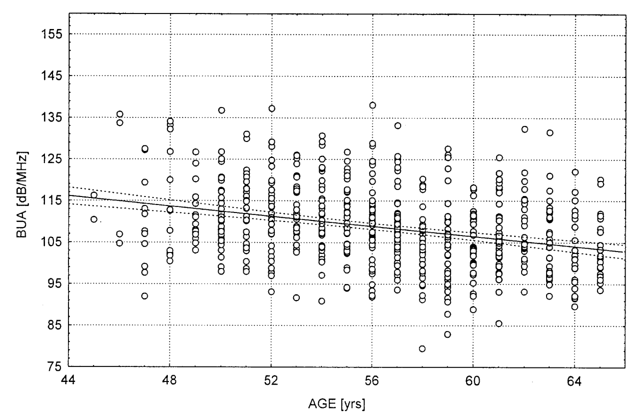

Figure 8. Simple linear regression between age and BUA in healthy women.

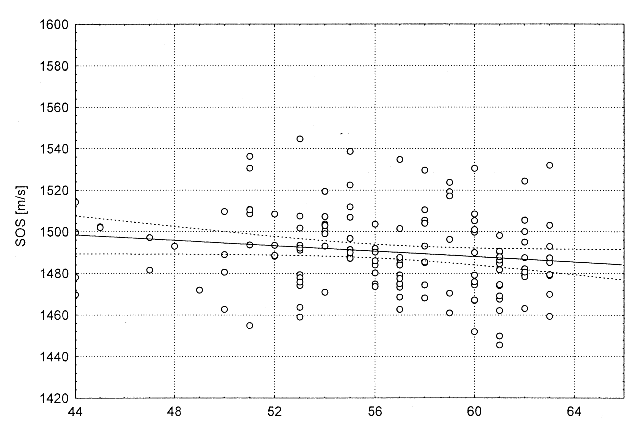

Figure 9. Simple linear regression between age and SOS in fractured women.

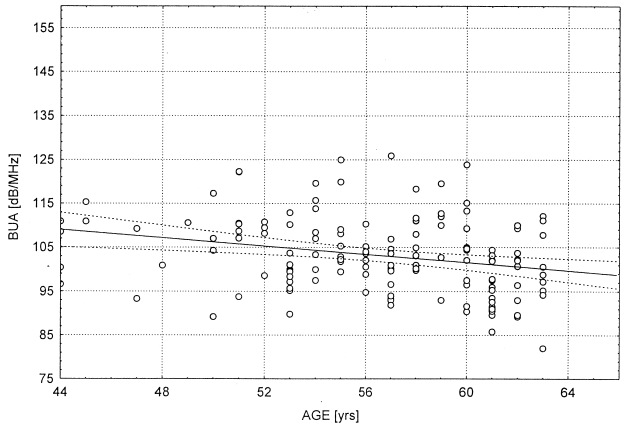

Figure 10. Simple linear regression between age and BUA in fractured women.

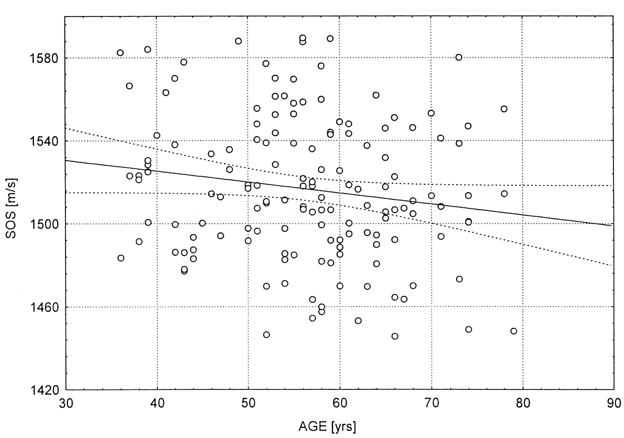

Figure 11. Simple linear regression between age and SOS in healthy men.

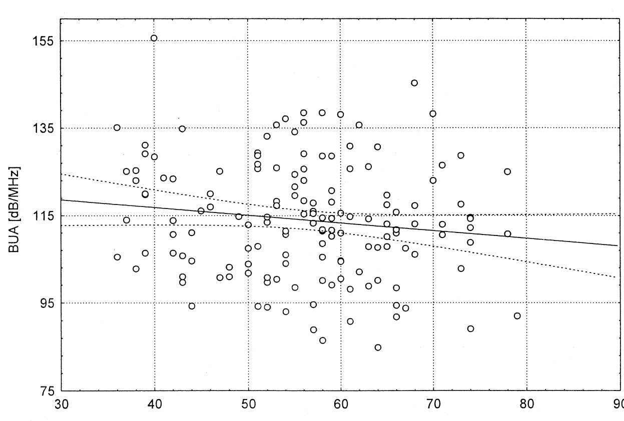

Figure 12. Simple linear regression between age and BUA in healthy men.

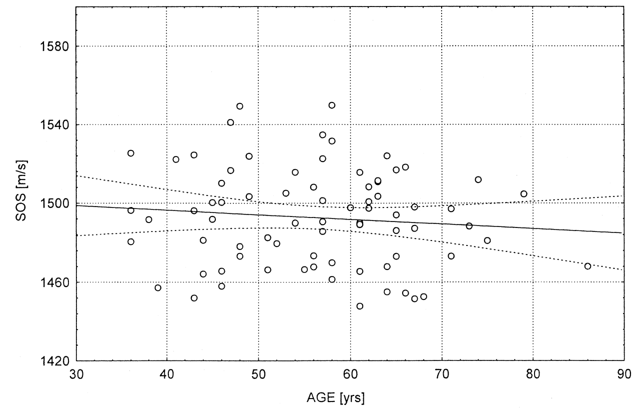

Figure 13. Simple linear regression between age and SOS in fractured men.

Discussion

Osteoporosis in men has received much less attention than in women. There are many studies with the use of qUS as a method for skeletal status evaluation in women,[4,6,7–9,12,13,18,19,22] but only a small number of such studies in men.[4,6,8,16] Several studies have shown the ability of ultrasound measurement at the calcaneus to discriminate between normal and osteoporotic women.[1–3,5,10,12,19,20] Discrimination between fractured and unfractured men has also been shown in cross-sectional studies.[14,15] On the other hand, in a retrospective study by Stewart et al.,[16] discrimination of vertebral deformations or fractures in group of 300 men using BUA was not possible. In the latter study, however, BUA measurement enabled detection of deformation or fracture in 300 women.

In our study, we were able to show fracture discrimination in both genders for SOS and BUA. Several studies conducted ROC analysis as a further evaluation of the ability of ultrasound to discriminate between people with and without fractures. In these studies, commonly performed in female populations, area under the curve was about 0.85 for SOS,[11,19,21] and for BUA 0.56,[14] 0.76,[17] or 0.79.[19] In the majority of previous studies, area under the curve was greater than in our study. In many studies, odds ratios were given for various types of fracture. In prospective studies by Hans et al.[5] and Bauer et al.[2] odds ratios for BUA were 2.0 and 1.7 for hip fracture and 2.4 for intertrochanteric

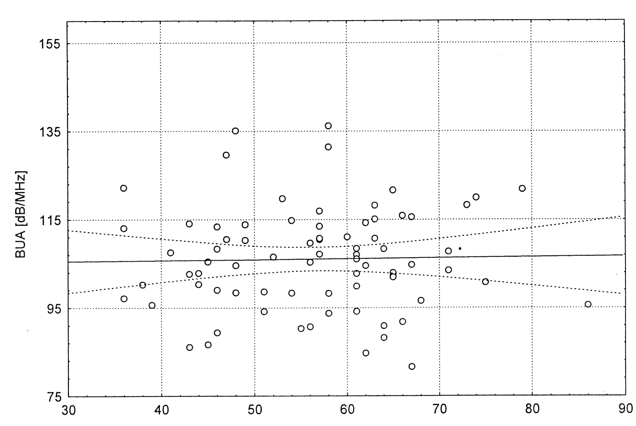

Figure 14. Simple linear regression between age and BUA in fractured men.

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Table 5. Multiple regression analysis

Multiple regression equation	r^2	SEE	p value
Group 1			
SOS = 1602.44 − 1.83 × age + 0.30 × weight − 0.05 × height	0.13	23.90	<0.00001
SOS = 1574.49 − 1.33 × age + 0.31 × weight − 0.03 × height − 0.64 × YSM	0.14	23.80	<0.00001
Group 2			
SOS = 1520.21 − 0.72 × age + 0.49 × weight − 0.14 × height	0.07	19.05	<0.05
SOS = 1551.87 − 0.23 × age + 0.44 × weight − 0.43 × height − 1.07 × YSM	0.12	18.72	<0.001
Group 3			
SOS = 1628.13 − 0.68 × age + 0.14 × weight − 0.49 × height	0.04	34.98	<0.14
Group 4			
SOS = 1570.18 − 0.27 × age + 0.48 × weight − 0.59 × height	0.05	24.46	<0.29
Group 1			
BUA = 103.17 − 0.57 × age + 0.24 × weight + 0.13 × height	0.17	8.69	<0.00001
BUA = 94.51 − 0.40 × age + 0.24 × weight + 0.14 × height − 0.22 × YSM	0.18	8.67	<0.00001
Group 2			
BUA = 113.11 − 0.49 × age + 0.32 × weight − 0.02 × height	0.17	7.91	<0.00001
BUA = 122.50 − 0.25 × age + 0.30 × weight − 0.13 × height − 0.36 × YSM	0.22	7.77	<0.00001
Group 3			
BUA = 144.36 − 0.20 × age + 0.18 × weight − 0.19 × height	0.04	13.18	<0.14
Group 4			
BUA = 98.14 + 0.04 × age + 0.33 × weight − 0.12 × height	0.10	11.18	<0.054

KEY: BUA, broadband ultrasound attenuation; SEE, standard error; SOS, speed of sound; YSM, years since menopause.

fracture, respectively. In a study conducted in men the odds ratio for low trauma fracture was 1.62 for sound velocity.[14] Odds ratios obtained in the current study were similar to other data, except for BUA in men, which was 1.05. Because of the small number of studies in male populations it is difficult to draw conclusions from these findings and further evaluation is necessary.

Age-related changes in our male population were less pronounced than those in the female population, but general trends were negative, except for the correlation between age and BUA in osteoporotic men. These differences were confirmed by Fisher's exact test and may be partly connected with a wider age range in men. In healthy men, linear regression analysis of ultrasound variables and age showed lower r values than those noted by Moris et al.[8] (age [SOS], $r = -0.64$, age [BUA] $r = -0.70$).

In healthy women, linear regression analysis of ultrasound variables and age showed lower r values than those obtained by Cepollaro et al.[4] (age [SOS], $r = -0.44$; age [BUA], $r = -0.45$) and by Schott et al.[13]: ($r = -0.66$; $r = -0.56$, respectively). A comparison between healthy and osteoporotic populations provides especially interesting, unexpected information on age-related changes. In both genders, the age-related decrease is clearly higher in the healthy groups. Thus, we can infer that in fractured individuals the decrease in ultrasound values occurred earlier and/or peak values of SOS and BUA were lower. Because no data concerning age-related changes in osteoporotic male and female populations are available in the literature, a direct comparison is not possible.

A comparison between qUS parameters and body size in men and women shows that both SOS and BUA are more dependent on body size in women. In men, only two significant correlations of BUA with body mass index (BMI) and BUA with weight were noted in the osteoporotic group. Intergender differences were also observed on multiple regression analysis. Weight showed a generally stronger positive influence on BUA and SOS in women than in men. Height influenced SOS negatively in both genders (except BUA in healthy women) and this influence was greater in men. A comparison of multiple regression analyses revealed that both ultrasound variables were clearly more dependent on all factors analyzed (age, weight, height) in women than in men.

It can be concluded that ultrasound measurement at the calcaneus is able to discriminate between normal male/female and osteoporotic male/female populations in a similar manner. Women had higher rates of decrease in BUA and SOS with age than men, and this decrease was higher in normal individuals in both genders. Distinct differences were noted between genders in regard to correlations of ultrasound parameters with body size.

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