

# Ultrasound attenuation of the calcaneus in normal subjects and in patients with wrist fracture

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We determined broadband ultrasound attenuation (BUA) of the calcaneus, and bone mineral density (BMD) of the spine, proximal femur and radius in 137 healthy subjects (79 women and 58 men) and in 56 women with Colles' fracture. The repeated measurements on 9 healthy subjects indicated a short-term reproducibility (coefficient of variation) of 4 percent for BUA. There was a small (7 percent) but significant difference in BUA between normal men and women. The age-dependence in normal subjects was weak. When all the study subjects were pooled, modest correlations between BUA of

the calcaneus and BMD at all measured skeletal sites were found ( $r_s$  values 0.3-0.4). However, it was not possible to make an accurate prediction of the axial BMD, using BUA.

BUA values were 13 percent lower in the wrist fracture patients than in the age-matched normals. In general, BUA could discriminate the fracture patients from normals as effectively as BMD. As suggested by the physical theory of ultrasound attenuation, our results support the idea that BUA reflects not only the bone density but also other factors related to the structural properties of bone.

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Recent reports indicate that broadband ultrasound attenuation (BUA) of the calcaneus correlates with single-photon absorptiometry (SPA) and quantitative computed tomography (QCT) of the radius (Poll et al. 1986, Smith et al. 1987) as well as with the axial bone mineral density (BMD) measured by dual-photon absorptiometry (DPA) or dual-energy X-ray absorptiometry (DXA) (Baran et al. 1988, Rossman et al. 1989). Unfortunately, the standard error of estimate has often been relatively high for these BUA techniques. Thus, the prediction of the axial BMD, using BUA of the calcaneus, has not proved to be acceptable. In addition, the BUA data on fracture patients are still scarce.

We have analyzed the relationship between BUA of the calcaneus and BMD measured by DXA and SPA at various skeletal sites in normal subjects, and in patients with wrist fracture. The short-term precision of the BUA method was determined.

## Subjects and methods

The initial study group (normal subjects) consisted of 79 women and 58 men ranging in age from 20 to

78 years. 34 women were postmenopausal. The normal subjects were free of any disease or medication known to affect bone metabolism. The fracture group consisted of 56 women, treated for a Colles' fracture, mean 1.5, SD 0.5 years before the measurement (Table 1). All study subjects were completely ambulatory. However, no definite subgroups could

Table 1. Mean values, SD for age, weight, height, BMD and BUA in study subjects

	Normal men (n 58)		Normal women (n 79)		Wrist fracture (n 56)	
Age	49	17	49	16	65	5.8
Weight (kg)	76	9.1	65	9.3	65	8.9
Height (cm)	176	7.3	163	6.3	159	6.0
BMD (g/cm <sup>2</sup> )						
L2-L4	1.22	0.16	1.13	0.15	0.98	0.14
Femoral neck	1.00	0.15	0.91	0.13	0.78	0.11
Ward's triangle	0.88	0.20	0.83	0.15	0.65	0.14
Trochanter	0.93	0.13	0.83	0.11	0.73	0.13
Distal radius	0.56	0.07	0.45	0.08	-	-
Proximal radius	0.76	0.07	0.62	0.08	-	-
BUA (dB/MHz)	76	13	71	16	59	13

Table 2. BUA (mean, SD, dB/MHz) of the calcaneus in normal men (n 58) and women (n 79)

Age	20-29	30-39	40-49	50-59	60-69	70-78
Men	77 11	74 16	71 13	80 16	75 12	75 16
Number	12	8	9	9	12	8
Women	80 22	67 14	75 12	71 18	65 13*	68 16
Number	9	16	19	14	12	9

\* $P < 0.05$  (not adjusted for multiple comparisons)

be created according to weight-bearing activity. Due to equal physical activity before and after the wrist fracture, the time interval before the measurement was considered to have a negligible effect on the bone status of these patients. The normal subjects were recruited by advertisements and the fracture patients attended our hospital. Informed consent was obtained from all subjects. The study was approved by the Ethics Committee of Kuopio University Hospital.

The measurement of BUA in the left heel was performed using the Walker Sonix UBA 575 device (Walker Sonix, Inc., Worcester, MA, U.S.A.). The method has been described recently (Baran et al. 1991, Truscott et al. 1992). Briefly, the patient sits with his/her foot immersed in a water bath. The heel is positioned with a pneumatically-controlled support between the transducers, which scan rectilinearly around the region of minimum density in the calcaneus. The technique measures the attenuation of an ultrasound signal by bone as a function of ultrasound frequency. The precision of the BUA technique was studied using repeated measurements in nine healthy subjects aged 25-44 (mean age 35, SD 6) years. Each subject was measured twice with a 10-min interval and re-positioning of the foot between the measurements.

SPA was performed in the forearm at two standard sites (1/10 metaphyseal bone of the distal radius and 1/3 cortical site of the radius) using a rectilinear scanner with an  $^{125}\text{I}$  source (Lunar SP2, Lunar Radiation Corporation, Madison, WI, U.S.A.). The reproducibility (coefficient of variation, CV) of SPA in our hospital is 4.3 percent for the distal radius and 1.2 percent for the radius shaft. Forearm measurements were not performed in the patients with wrist fracture.

BMD of the lumbar spine (L2-L4) and proximal femur (femoral neck, Ward's triangle, trochanter major) was measured using dual-energy X-ray absorptiometry (Lunar DPX, Lunar Radiation Corporation, Madison, WI, U.S.A.). The CV of our DXA measurements in the lumbar spine, femoral

neck, Ward's triangle and trochanter are 0.9, 1.5, 3.1, and 2.2 percent, respectively (Kröger et al. 1992).

### Statistical analysis

Kolmogorov-Smirnov's test was used to examine normality of the variables. Since the sample sizes were relatively small and the variables in the subgroups were frequently not normally distributed, we preferred nonparametric methods in the statistical analyses. We used Spearman's correlation analysis to test the dependence of BUA with age, weight, height and BMD. The Mann-Whitney U-test was used to test the differences between the study groups.

The Z-score shows the patient's result as the difference from the mean of the age-matched controls divided by the standard deviation of this mean. The T-score refers to the peak bone mass of young normal adults and is calculated similarly to the Z-score (Grampp et al. 1993). We calculated the T-scores for wrist fracture patients using the mean BMD and the BUA of young women aged 20-40 years. The age-matched Z-scores were calculated using the mean BMD and BUA values of normal women aged more than 50 years. The mean ages of these control groups were 32 (n 24) and 64 (n 35), respectively.

### Results

The short-term reproducibility of our BUA technique was 3.5 percent. As compared to women, the men over the age of 50 years had slightly higher BUA values (Table 2). There was also a difference between the sexes when the age-groups were pooled (76, SD 13 dB/MHz (men) vs. 71, SD 16 dB/MHz (women),  $P 0.04$ ) (Table 1).

The relationships of BUA with age, weight or height were weak. However, when the normal subjects and the fracture cases were pooled, these correlations were significant (Table 3). In contrast, the axial and peripheral BMD correlated strongly with age, weight and height (data not shown). The mean BUA was not lower in normal postmenopausal

Table 3. Correlation coefficients ( $r_s$ ) between BUA and age, weight and height and their significance in the study groups

BUA	n	Age	Weight	Height
Normal men	58	-0.02	0.11	0.12
Normal women	79	-0.14	-0.15	-0.01
All normals	137	-0.11	0.03	0.18*
Wrist fracture	56	-0.26*	0.10	0.07
All women	135	-0.33***	-0.05	0.13
All cases	193	-0.29***	0.14*	0.29***

\*  $P < 0.05$ , \*\*\*  $< 0.001$

women as compared to premenopausal women (67, SD 15 vs. 73, SD 16 dB/MHz,  $P$  0.1).

The correlations between BUA of the calcaneus and BMD at the axial and peripheral skeleton sites in normal subjects were moderate and very similar regarding the proximal femur and radius, whereas the correlation between BUA and lumbar BMD was slightly lower. Generally, the correlations between BUA and BMD were stronger in normal men than in normal women. When all the women were analyzed together, significant correlations between BUA and BMD were found (Table 4).

In wrist fracture patients, the lowest T-score was found in spinal BMD and the lowest Z-score in trochanteric BMD (Table 5). The Z-scores were quite similar for BUA, femoral neck BMD and Ward's triangle BMD. The differences between the wrist fracture cases and age-matched normals reached significance in all measurement sites.

## Discussion

In previous studies, the short-term reproducibility of BUA measurements in vivo has varied from 2.9 to 4.6 percent (Resch et al. 1990, Baran et al. 1991, Damilakis et al. 1992, Truscott et al. 1992, Herd et al. 1992). The reproducibility obtained in our study (3.5 percent) was similar to that found in these previous reports. Preliminary reports have suggested that the long-term precision of BUA is double that of the short-term precision (Salamone et al. 1992).

BUA data in men are scarce (Zagzebski et al. 1991). We found a small difference in BUA between the sexes. The difference was most apparent after the age of 50 years. The small difference between the

Table 4. Correlations between BUA of the calcaneus and BMD at different skeletal sites in normals, all women, and all study subjects

BUA	n	Spine L2-L4	Femoral neck	Ward's triangle	Troch.	Distal radius	Prox. radius
Normals	137	0.18*	0.27**	0.21**	0.23**	0.29***	0.31***
Men	58	0.28*	0.37**	0.40**	0.37**	0.21	0.30*
Women	79	0.06	0.14	0.05	0.06	0.25*	0.24*
All women	135 <sup>a</sup>	0.26**	0.34***	0.33***	0.27**	0.25* <sup>a</sup>	0.24* <sup>a</sup>
All cases	193 <sup>b</sup>	0.34***	0.43***	0.41***	0.39***	0.29*** <sup>b</sup>	0.31*** <sup>b</sup>

\*  $P < 0.05$ , \*\*  $< 0.01$ , \*\*\*  $< 0.001$

<sup>a</sup> n 79 and <sup>b</sup> n 137 in forearm measurements

Table 5. BMD and BUA in patients with wrist fractures (n 56), expressed as percentages, and as mean T-scores of young normals and mean Z-scores of age-matched normals (with 95% confidence limits)

Wrist fracture patients (n 56) compared with	BMD				BUA
	Spine L2-L4	Femoral neck	Ward's triangle	Troch.	Calcaneus
<i>Young normals (20-40 yrs)</i>					
Percent	81***	81***	70***	88***	83**
T-score	-2.3 (-2.0; -2.7)	-1.5 (-1.2; -1.7)	-1.9 (-1.6; -2.1)	-0.9 (-0.6; -1.2)	-0.7 (-0.5; -0.9)
<i>Age-matched normals (&gt;50 yrs)</i>					
Percent	95*	92**	88***	89***	87**
Z-score	-0.4 (-0.1; -0.7)	-0.6 (-0.3; -0.9)	-0.7 (-0.4; -0.9)	-0.9 (-0.6; -1.3)	-0.6 (-0.4; -0.8)

\*  $P < 0.05$ , \*\*  $< 0.01$ , \*\*\*  $< 0.001$ , significant difference between fracture group and normal group (Mann-Whitney test)

sexes may also be an indication of the larger calcaneus in men (Langton 1987). The sex differences were more distinct in BMD values. The axial BMD has also been found to be higher in men, but when corrected for weight and height there are no differences in the lumbar or femoral BMD values between men and women under the age of 60 years (Kröger and Laitinen 1992).

In our study the age dependency of BUA values was weak in normal subjects. The correlations between BUA and body weight or height were also low. These findings disagree with the BMD measurements of the os calcis (Lancaster et al. 1989). Agren et al. (1991) have reported a decrease in BUA with age ( $r = -0.45$ ) in a heterogeneous group of normal and osteoporotic women. Similarly, in our study, age dependency was significant when the fracture cases were included in the analysis. In contrast to the study by Herd et al. (1992), we found no decrease in BUA immediately after the menopause. Our findings suggest that, in normal subjects, the age dependency of BUA is weak. However, the small number of study subjects may partly explain the lack of correlation. Instead, the variation in BUA values among normal subjects seems to be great. Our results are in accordance with the recent BUA data of Damilakis et al. (1992). Similarly, Massie et al. (1993) have reported weak correlations between BUA and age or parameters for body size.

A high correlation ( $r$  values from 0.6 to 0.8) between BUA of the calcaneus and BMD at the lumbar spine or at the femoral neck has been reported (Baran et al. 1988, McCloskey et al. 1990, Baran et al. 1991, Truscott et al. 1992). The correlation between BUA and BMD at the distal radius is almost the same (Rossman et al. 1989, McCloskey 1990). Most of these studies have included both normal subjects and osteopenic patients in the analysis, which may partly explain the high  $r$  values. Recently, considerably poorer correlations between BUA and axial BMD have been demonstrated ( $r$  values from 0.2 to 0.4) (Massie et al. 1993, Young et al. 1993). In our study, correlations were found between BUA in the os calcis and BMD in most of the measured skeletal sites, especially when the study groups were combined. Normal women showed the weakest correlations. Despite these correlations, the usefulness of BUA in predicting axial BMD does not seem to be sufficiently good. In spite of physical differences in gamma/x-ray absorption and ultrasound attenuation (Langton et al. 1987, 1990), previous studies suggest a high correlation ( $r$  0.8–0.9) of BUA with bone mineral content in vitro samples (McKelvie and Palmer 1987, Tavakoli

and Evans 1991). Therefore, the fact that correlation of BMD between different skeletal sites is not particularly strong (Wasnich et al. 1985, Pocock et al. 1986) may partly explain the rather weak correlations found in the present study. Gluer et al. (1992) examined both BUA and single x-ray absorptiometry at the calcaneus and found correlation coefficients in the order of 0.6–0.7. Even though it was the same region of interest that was measured, 50 percent of the variability remained unexplained.

Obviously, the weak correlations in our study do not mean that BUA has no value in predicting fracture liability, which is the most fundamental goal of bone measurements. Instead, the physical theory of ultrasound attenuation suggests that BUA provides new information that may be related to the structural and mechanical status of the bone. A recent in vitro study suggests that BUA reflects anisotropical characteristics of trabecular bone (Gluer et al. 1993).

Vertebral or hip fracture patients have lower BUA values than age-matched controls (Baran et al. 1988, Agren et al. 1991). BUA values of postmenopausal women with vertebral osteoporotic fractures have been reported to be 35 percent lower than those in normal perimenopausal women (McCloskey et al. 1990). In a prospective study, the risk of hip fractures was increased in elderly women with low BUA values (Porter et al. 1990b).

Previous authors have found 0.6–0.7 SD reduction of spinal bone density in patients with Colles' fracture (Krolner et al. 1982, Härmä and Karjalainen 1986). Although Colles' fracture is considered to be an osteoporotic fracture, such fractures result from considerable trauma, even when they occur in postmenopausal women. Thus, the women with Colles' fracture may represent a group with mild osteoporosis. In a population-based study using ultrasound, the women with wrist fracture had a decreased BUA at the calcaneus when compared with age-matched controls, although there was a considerable overlap between the groups (Porter et al. 1990a).

In our study, wrist fracture patients had 5–12 percent lower BMD values and 13 percent lower BUA values as compared with healthy age-matched controls. When the values were compared with young adult women, the differences were more marked (12–30 percent). Although women with Colles' fracture have marked *absolute* osteopenia, obviously there is only slight *relative* osteopenia in these patients. In fact, Colles' fracture patients may have preferential osteopenia in the forearm (Eastell et al. 1989). Unfortunately, we had no opportunity to measure forearm BMD in our wrist fracture patients. Our results suggest that BUA distinguishes wrist

fracture cases from controls as well as most of the axial BMD measurements.

Our findings suggest that BUA is only partially related to the bone mineral density. For the present, it is not known to what extent BUA is related to bone strength and structure (McKelvie and Palmer 1987). Although the correlation between BUA of the calcaneus and axial BMD was not high, the utility of BUA in recognizing wrist fracture cases was relatively good. Since it is a radiation-free and rapid technique, BUA may prove to be suitable in selected screening of osteoporosis. However, only large-scale prospective studies can provide reliable data on the fracture risk and fracture threshold of the measurement techniques. The large intrapopulation variation and only moderate precision diminish the value of BUA in the diagnosis and monitoring of osteoporosis in a given individual.

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