Osteoporos Int (1998) 8:449–454

Osteoporosis International

Original Article

The Influence of Physical Activity and Fractures on Ultrasound Parameters in Elderly People

W. C. Graafmans[1], L. M. Bouter[1,2] and P. Lips[1,3]

[1]Institute for Research in Extramural Medicine (EMGO Institute) and [2]Department of Epidemiology and Biostatistics, Vrije Universiteit, Amsterdam; and [3]Department of Endocrinology, Academisch Ziekenhuis Vrije Universiteit, Amsterdam, The Netherlands

Abstract. In this cross-sectional study we investigated the relationship between ultrasound measurements in the calcaneus versus daily physical activity and fractures sustained in the past in elderly subjects. Ultrasound measurements were performed at both heels, which enabled us to examine determinants of differences between contralateral heels. Participants were 132 men and 578 women, aged 70 years and over (mean age and standard deviation (SD): 83 ± 6 years), living in homes for the elderly ($n=343$) or apartment houses for the elderly ($n=367$). Broadband ultrasound attenuation (BUA) and speed of sound (SOS) were measured in the right and left calcaneus. The median difference (and interquartile range) between the two heels for BUA and SOS, expressed as a percentage of the mean value for each individual, was 9.6% (4.2–15.7%) and 1.0% (0.4–1.7%), corresponding to 25% and 40% of the study population SD, respectively. Greater differences in BUA between the two heels were associated with variables indicating poorer functional status, such as past fractures at the lower extremities. The level of daily physical activity was obtained by means of a questionnaire regarding household and leisure activities. Subsequently sumscores were calculated for daily physical activity and a subscore indicating weight-bearing physical activity. After adjustment for age, gender, residence, and body weight, physical activity scores were positively linearly related to both BUA and SOS. Each 5 point increase on the weight-bearing physical activity score, corresponding to, for example, walking for 2.5 h per week, was associated with a difference in BUA of 4.7 dB/MHz and in SOS of 5.1 m/s, which is similar to the differences associated with 10 kg higher body weight, or 10 years younger age. After the age of 50 years, 47 subjects had fractured a hip, 61 subjects had sustained another lower extremity fracture, 104 subjects a wrist fracture, and 62 subjects another upper extremity fracture. After adjusting for age, gender and residence, odds ratios for all fracture types in the lowest terciles of BUA and SOS versus the highest terciles ranged from 1.9 to 3.8. This study showed significant differences in ultrasound measurements between the left and the right heel, indicating that measurements at both sides are necessary for optimal evaluation of bone strength. Furthermore, after careful adjustments, ultrasound parameters had higher values with higher daily physical activity in elderly subjects and discriminated subjects with a history of fracture from those without.

Keywords: Bone; Elderly; Fractures; Physical activity; Ultrasound

Correspondence and ofprint requests to: Dr P. Lips, EMGO Institute, Faculteit der Geneeskunde, Vrije Universiteit, Van der Boechorststraat 7, 1081 BT Amsterdam, The Netherlands.

Introduction

The incidence of fractures rises exponentially with aging and leads to disability that may be transient (e.g., after a wrist fracture) or permanent (e.g., following a hip fracture). Fractures are multi-causal events in which bone strength plays a dominant role [1]. Bone strength is usually evaluated by measurement of bone mineral density (BMD), which has been shown to predict fractures [2–6]. Recently, ultrasound measurements of bone have been suggested for the evaluation of bone strength [7,8]. This type of measurement is relatively simple and can be done at the calcaneus. Ultrasound parameters are associated with bone mass and may supply information about the structure of bone tissue as well, which is another major component of bone strength [9]. Several studies suggest that ultrasound measurements at the calcaneus may be useful for estimating fracture risk [10,11].

In contrast to BMD, measured at predominant fracture sites, ultrasound parameters are not determined at a skeletal site of interest for its fracture risk. Characteristics of the measured site in the skeleton may have implications for interpretation, for example with respect to physical activity [12,13]. The calcaneus has a central position in bearing body weight. Therefore, ultrasound parameters in the calcaneus may be sensitive to small differences in physical activity, especially weight-bearing activity. With advancing age, daily physical activities such as housekeeping, shopping and leisure activities increasingly determine the total amount of physical activity, since occupational activities and heavy-intensity activities decline with age [14]. Although few intervention studies suggest a positive effect of physical activity on BMD [15–17], the relationship between daily physical activity and bone characteristics remains to be established. Fractures at the lower extremities may lead to immobilization, which results in a reduced level of physical activity and bone loss [18], especially in the fractured limb compared with the contralateral limb [19]. Therefore, in the relationships between ultrasound parameters versus physical activity and past fractures, measurements obtained at the nonfractured side only were used for analysis. In this cross-sectional study we investigated ultrasound parameters measured at both heels in an elderly institutionalized population regarding side difference, daily physical activity and fracture history.

Subjects and Methods

During a 1-year period, subjects were recruited to participate in a prospective study on the prediction of fracture risk by ultrasound measurements at the calcaneus. This prospective study is currently in progress. Participants were recruited from seven homes and apartment houses for the elderly in Amsterdam and its vicinity. Some care is provided in Dutch homes for the elderly, although less than in a nursing home. Inclusion criteria were 70 years of age or older and no severe cognitive impairment, as judged by the personnel of the care facility. Eligible subjects were sent a letter with information about the study. Subsequently they were asked to participate during a visit by our research workers. The protocol was approved by the ethics review board of the Academic Hospital of the Vrije Universiteit.

Ultrasound measurements were performed using the CUBA Clinical instrument (McCue Ultrasonics, Winchester, UK). Two transducers (emitting and receiving) faced with silicone rubber coupling pads are placed in direct contact on either side of the heel, using a coupling gel. Double measurements of broadband ultrasound attenuation (BUA, dB/MHz) and speed of sound (SOS, m/s) were done in the right and left heel, with repositioning between measurements. Measurements were performed at the residence of the participants. Precision of BUA and SOS measurements (expressed as coefficient of variation) are 3.4% and 1.4% [12].

Data on daily physical activity in the previous year were obtained using a validated questionnaire for elderly persons [20]. Frequency (times per week and months per year) and duration of different activities were registered: household activities (e.g., cleaning and shopping), sports activities (e.g., swimming and cycling), and leisure activities (e.g., going for a walk). For each activity the energy expenditure was calculated and subsequently a score was calculated by summation of all activities for each person during the past year [20]. The activity score in a previous study in elderly people ranged from 2 to approximately 30 [20]. The weight-bearing activity score was obtained by modifying the daily physical activity score: activities that do not involve loads as a consequence of body weight in an upright position (e.g., swimming and cycling) were excluded from the activity sumscore.

Additional information about possible confounders of the relationship between physical activity and ultrasound parameters was obtained on the day of the ultrasound measurements: body weight was measured, and information about age, gender, residence and the use of corticosteroids was obtained by means of a questionnaire. Possible determinants of differences between the ultrasound parameters in the right and left heel were obtained by means of a questionnaire: the use of a walking aid (including occasional use of a wheelchair), motor dexterity and fracture history. In case of doubt, the information obtained with the questionnaire in those living in homes for the elderly was checked with the nurse of the residence.

Data Analysis

Mean ultrasound parameters were calculated from four measurements (two in the right and two in the left heel). The difference between the two heels was expressed as a percentage of the mean value for each participant. Possible determinants of the side differences in ultrasound parameters (i.e., dexterity, age, the use of a walking aid, a history of lower extremity fractures, and the value of the ultrasound measurements) were analyzed using linear regression analysis, using the log-transformed absolute difference between the two sides as a dependent variable.

Fractures of the lower extremities may lead to immobilization and will affect the ultrasound measurements and the level of physical activity. Therefore, in those subjects who had suffered a hip or other lower extremity fracture in one limb after the age of 50 years, ultrasound measurements at the nonfractured side only were used for analysis, instead of the mean of the two sides.

The relationship of the physical activity score with ultrasound parameters was evaluated in a multiple regression analysis, controlling for age, gender, residence, body weight and the use of corticosteroids. A possible significant interaction between physical activity and gender was examined in the regression model. The association between physical activity and the ultrasound parameters was expressed as the difference in ultrasound parameters for every 5 point increase in activity score, calculated by multiplying the β of the activity score by 5 in the linear regression model. Fractures in relation to ultrasound measurements, were analysed in logistic regression models, controlling for age, gender and residence. Ultrasound parameters were entered as categorical variables since there was no linear relationship. Ultrasound parameters were divided into terciles, which resulted in sufficient numbers of fractures in each tercile for meaningful evaluation. Adjusted odds ratios for the relationship between ultrasound parameters and fractures were presented on a logarithmic scale, which enables a more straightforward interpretation of the logistic model with symmetric confidence intervals. As for the relationship between upper extremity fractures and ultrasound parameters, the analysis was also performed excluding those who had sustained a lower extremity fracture after the age 50 years, since this may have led to immobilization and therefore affected the ultrasound measurements.

Table 1. Study population characteristics (*n*=710)

Parameter		
	Mean (Standard Deviation)	
Age (years)	82.8 (5.9)	
Years since menopause[a]	34.4 (7.9)	
BUA (dB/MHz)[b]	60.8 (20.6)	
SOS (m/s)[b]	1468.6 (34.3)	
Body weight (kg)	68.0 (12.7)	
	Median (Range)	*IQR*
Activity score[c]	3.0 (0.0–22.8)	1.3–5.7
Weight-bearing activity score	1.3 (0.0–15.5)	0.4–2.9

For skewed parameters median, range and 25th and 75th percentiles (IQR) are presented.
[a]Years since menopause obtained in 499 women.
[b]BUA (broadband ultrasound attenuation) and SOS (speed of sound) were not measured in three subjects.
[c]According to a questionnaire on household, sports and leisure activities.

Results

During a 1-year period, 710 subjects (132 men, 578 women) were recruited from homes for the elderly (343) and apartment houses for the elderly (367). Table 1 shows the study population characteristics. Ultrasound parameters were not measured in three participants, and only on one side in seven participants. Missing values were due to edema, fractured calcaneus, and other disabilities that made measurement on both sides impossible.

The difference between the ultrasound parameters on the left and right sides was calculated for 700 subjects. The mean (and standard deviation) and median (and interquartile range) difference between the two heels for BUA were 6.8 (6.0) dB/MHz and 5.0 (2.0–9.5) dB/MHz, respectively, and for SOS 18.8 (20.5) m/s and 13.6 (5.5–24.7) m/s. The median difference (and interquartile range) in BUA and SOS, expressed as a percentage of the mean value of both measurements for the individual at issue, was 9.6% (4.2–15.7%) and 1.0% (0.4–1.7%), respectively. The difference in ultrasound parameters between the two heels was not related to dexterity ($p>0.8$). The difference in BUA between the two heels was higher with advancing age ($p = 0.03$) and the use of a walking aid ($p = 0.007$). Furthermore, a history of hip fracture or other lower extremity fracture ($p = 0.001$), and lower BUA values ($p = 0.004$), were independently related to this difference. No relationships were found between any of these factors and the difference in SOS between the two heels. With respect to those subjects who suffered a hip or other lower extremity fracture at one side ($n = 77$), BUA and SOS were lower at the fractured side: mean difference and SD, expressed as percentage of mean values were 5.0% (20.9) and 0.2% (1.5), respectively.

The physical activity score was linearly related to BUA and SOS. The activity score was significantly higher for men than for women, after adjustment for age: 1.5 (0.9–2.1) points on the scale. The mean difference and 95% confidence interval (95% CI) for each 5 point increase on the physical activity score for BUA and SOS were calculated for men (6.0 (1.9–10.5) dB/MHz and 8.5 (2.0–15.1) m/s, respectively) and for women (3.5 (1.1–5.6) dB/MHz and 6.5 (2.0–11.0) m/s, respectively). After including the physical activity score in a multiple regression model, along with possible confounders, physical activity was still significantly related to BUA and SOS (Table 2). Regarding the weight-bearing activity score, the mean difference and 95% CI for each 5 point increase on the activity score for BUA and SOS were calculated for men (7.3 (0.4–14.1) dB/MHz and 6.4 (–4.2-17.0) m/s, respectively) and women (5.2 (1.8–8.6) dB/MHz and 9.0 (2.2–15.8) m/s, respectively). After adjustment for age, gender, residence and body weight, the differences (mean and 95% CI) in BUA and SOS for each 5 point increase on the weight-bearing physical activity score were 4.7 (1.7–7.7) dB/MHz and 5.1 (–0.6–10.9) m/s, respectively. The relationships between physical activity and weight-bearing activity versus ultrasound parameters were similar after exclusion of subjects who sustained a hip fracture and/or another lower extremity fracture ($n = 102$). Although the unadjusted relationships between physical activity and weight-bearing physical activity versus ultrasound parameters were different between men and women, no significant interaction was found between (weight-

Table 2. The effect of physical activity, gender, age, body weight, and residence on broadband ultrasound attenuation (BUA) and speed of sound (SOS) in the calcaneus

	BUA (dB/MHz)		SOS (m/s)	
	Mean value	95% CI	Mean value	95% CI
Physical activity score (every 5 points higher)	3.0	0.9 to 4.9	3.8	0.1 to 7.6
Female gender (vs men)	–20.0	–16.7 to –23.3	–9.7	–3.4 to –16.1
Age (every 10 years older)	–3.5	–1.0 to –5.9	–6.3	–1.7 to –10.9
Body weight (every 10 kg heavier)	4.2	3.1 to 5.3	7.1	5.1 to 9.1
Home for the elderly (vs apartment houses)	–2.3	0.5 to –5.1	–7.8	–2.6 to –13.1

Each variable is adjusted for all other variables in the table. Mean values and 95% confidence intervals (CI) were obtained by multiple linear regression (n=700[a]), involving all variables simultaneously.
[a]Complete data sets were not obtained in 10 subjects due to missing values on body weight and ultrasound parameters at the nonfractured side.

Table 3. Number of subjects who had suffered fractures after the age of 50 years

Type of fracture	No. of subjects
Hip	47
Other lower extremity[a]	61
Wrist	104
Other upper extremity[b]	62
Other[c]	22

[a]Femur, tibia, ankle and foot fractures.
[b]Humerus, clavicle and hand fractures.
[c]Pelvis, rib, skull and known vertebral fractures.

bearing) physical activity and gender in relation to BUA and SOS in the multiple regression models (p>0.20). The relationship between physical activity and weight-bearing physical activity versus ultrasound parameters was not confounded by the use of corticosteroids (used by 36 participants, 5.1%) (p>0.90).

In retrospect, 234 subjects suffered 296 fractures after the age of 50 years. Table 3 shows the number of subjects who had suffered fractures. Fifty-one subjects had suffered more than one type of fracture and 10 subjects more than two types of fractures. BUA and SOS values were grouped in terciles. As already mentioned in Subjects and Methods, values of the nonfractured side were used in those with hip or other lower extremity fractures on one side. Mean values (and SD) of BUA and SOS in the lowest tercile were 39.9 (7.7) dB/MHz and 1433.1 (17.9) m/s, in the second tercile 58.5 (4.7) dB/MHz and 1466.9 (8.3) m/s and in the highest tercile 84.2 (13.7) dB/MHz and 1506.2 (23.0) m/s, respectively. The number of hip fractures in the lowest, middle and highest terciles was 27, 15 and 5 for BUA, and 30, 11 and 6 for SOS, respectively. Regarding wrist fractures, the equivalent values were 45, 44 and 14 for BUA, and 49, 30 and 24 for SOS:. BUA and SOS, adjusted for age, gender and residence, were related to hip, other lower extremity fractures, wrist, and other upper extremity fractures (Fig. 1). The remaining other fractures were not related to ultrasound parameters (data not shown). When repeating the analysis after excluding subjects with a history of lower extremity fractures, similar relationships

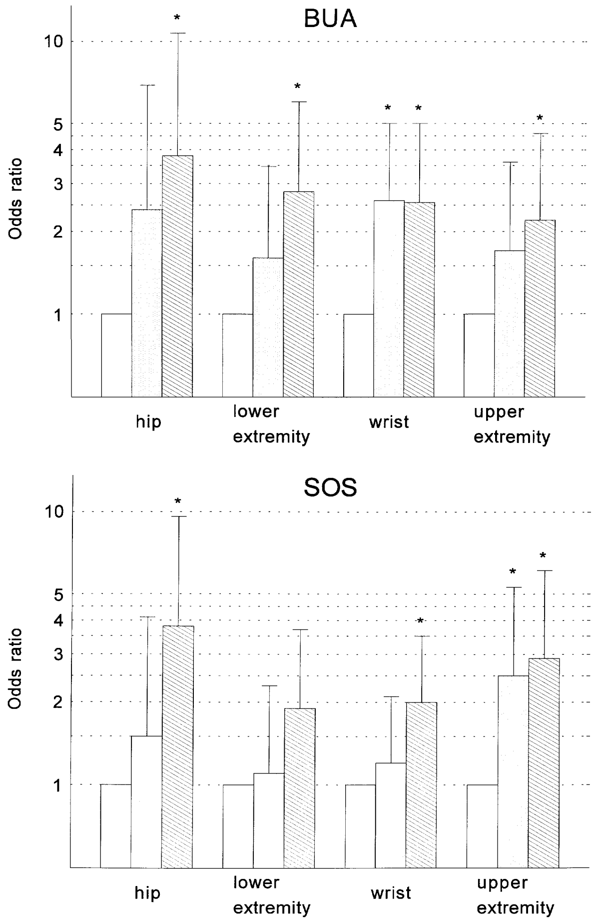

Fig. 1. The odds ratio (depicted on a log scale) for different fractures (i.e., hip, other lower extremity fractures, wrist, and other upper extremity fractures) adjusted for age, gender and residence in three terciles of BUA (*upper panel*) and SOS (*lower panel*). The *left bars* represent the highest tercile, indicating the reference group; the *middle bars* and the *right bars* denote the intermediate and lowest terciles, respectively. The error bars represent the upper half of the 95% confidence intervals. *p<0.05 indicates significant difference from the highest tercile.

were found between ultrasound parameters and upper extremity fractures; the adjusted odds ratios (95% CI) for wrist fractures in the middle and lowest terciles versus the highest tercile of BUA were 2.8 (1.4–5.8) and 2.6

(1.2–5.5) dB/MHz, and for SOS 1.4 (0.7–2.7) and 2.3 (1.2–4.3) m/s, respectively. The adjusted odds ratios (95% CI) for other upper extremity fractures in the middle and lowest terciles versus the highest tercile of BUA were 1.2 (0.5–2.8) and 1.7 (0.7–3.8) dB/MHz, and for SOS 3.8 (1.5–9.8) and 4.6 (1.8–12.1) m/s, respectively.

Discussion

This study shows that ultrasound measurements may differ substantially between opposing heels. Daily physical activity in elderly people was associated with ultrasound measurements, and ultrasound parameters discriminated between subjects with a history of fracture and those without. The adjusted odds ratio for fractures in the lowest versus the highest tercile of BUA and SOS ranged from 1.9 to 3.8. Previous studies also reported lower ultrasound measurement values in subjects with a history of fractures [21–23]. However, these results are hard to interpret since fractures may cause immobilization and consequently affect bone characteristics, especially in the fractured limb [18,19,24], and thus current measurements may not be related to values at the time of the fracture.

Suggesting a causal relationship in a cross-sectional study has some serious potential methodological flaws. However, lifestyle factors such as daily physical activity are difficult to investigate in a longitudinal setting since these factors are not prone to change over a few years. Several steps were taken to approximate a unidirectional relationship between physical activity versus ultrasound parameters and ultrasound parameters versus past fractures. Firstly, ultrasound measurements at the heel of a fractured lower limb were not used, but only the contralateral measurement was included in the analyses. Secondly, analyses were also performed excluding participants who suffered a lower extremity fracture, which might have led to immobilization. Thirdly, adjustments were made in multiple regression models for variables possibly affecting the examined relationship (i.e., age, gender, residence, body weight and the use of corticosteroids).

In subjects with a history of lower extremity fracture, ultrasound measurements were used that were obtained at the non-fractured side only. The difference in BMD between contralateral bones has been the subject of investigation before, and it has been suggested that routine BMD measurements at the hip should include both sides [25]. In this study substantial differences in calcaneal ultrasound parameters between the left and the right side were measured. Although the difference in SOS between the two sides is only 1% of mean SOS of both heels, it increases when expressed in relation to the range of measurements in the study population: the median difference in SOS between the two heels was 40% of the study population SD, and the median difference in BUA was 25% of the study population SD. The magnitude of this difference indicates a considerable risk of misclassifying bone status when only one side is measured. In accordance with previous results, left or right handedness was not related to the direction of this difference [25]. The functional division of motor tasks between the left and right hand may not apply to different use of the right and left leg. Several other factors were related to the difference in BUA between the two heels. All related factors may indicate the degree of disability: aging, the use of a walking aid, history of fractures of the lower extremities, and low BUA values. The lack of association between these factors and the difference in SOS may be due to the different bone properties being measured and the lower precision of SOS measurements [12].

A higher level of daily physical activity was associated with higher ultrasound measurements, in particular regarding BUA. This relationship was somewhat stronger in men than in women. However, the differences between men and women are well within the confidence intervals and no significant interaction between physical activity and gender could be detected in the regression models. Thus, although the results suggest a difference in effect of physical activity on ultrasound parameters between men and women, the power of this study was insufficient to examine this difference. Based on a multiple linear regression model, including physical activity and other determinants of ultrasound parameters, a comparison was made regarding the strength of the relationships with BUA and SOS (Table 2). The effect expressed for each 5 point increase in the activity score was similar to the effect of each 10 kg increase in body weight and each 10 year reduction in age, but less than the difference between men and women. An increase of 5 points on the activity score is equivalent to, for example, going for a walk or cycling for 2.5 h per week. Several intervention studies in elderly people have shown that especially weight-bearing activities, leading to high strains in the skeleton, may be beneficial to maintain bone mass [17,26,27], but other studies were unable to demonstrate such an effect of physical activity on bone mass [28,29]. Although these results suggest a protective effect of daily physical activity for skeletal integrity, physical activity in this very elderly population may be an indication of the level of physical activity in the past. However, it may be difficult to show independent relationships for past and present physical activity since they are strongly related.

This study showed a large difference in ultrasound measurements between opposing heels, indicating possible misclassification of bone status when based on unilateral measurements. Special attention is warranted in those with disabilities and lower extremity fractures. These results indicate that measurements at both sides are necessary for optimal evaluation of bone strength. Furthermore, daily physical activity is one of the more important determinants of bone characteristics, such as age and body weight. Although a prospective study design is preferred with regard to the prediction of fractures by ultrasound measurements, cross-sectional data revealed a strong relationship even after extensive adjustments.

References

1. Dempster DW, Lindsay R. Pathogenesis of osteoporosis. Lancet 1993;341:797–805.
2. Kanis JA, and the WHO Study Group. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: synopsis of a WHO report. Osteoporos Int 1994;4:368–81.
3. Black DM, Cummings SR, Melton LJ III. Appendicular bone mineral and a woman's lifetime risk of hip fracture. J Bone Miner Res 1992;7:639–46.
4. Cummings SR, Black DM, Nevitt MC. Bone density at various sites for prediction of hip fractures. Lancet 1993;341:72–5.
5. Hui SL, Slemenda CW, Johnston CC. Baseline measurements of bone mass predicts fracture in white women. Ann Intern Med 1989;111:355–61.
6. Seeley DG, Browner WS, Nevitt MC, et al. Which fractures are associated with low appendicular bone mass in elderly women? Ann Intern Med 1991;115:837–42.
7. Langton CM, Palmer SB, Porter RW. The measurement of broadband ultrasonic attenuation in cancellous bone. Eng Med 1984;13:89–91.
8. Greenfield MA, Craven JD, Huddleston A, Kehrer ML, Wishko D, Stern R. Measurement of the velocity of ultrasound in human cortical bone in vivo. Radiology 1981;138:701–10.
9. Agren M, Karellas A, Leahey D, Marks S, Baran D. Ultrasound attenuation of the calcaneus: a sensitive and specific discriminator of osteopenia in postmenopausal women. Calcif Tissue Int 1991;48:240–4.
10. Porter RW, Miller CG, Grainger D, Palmer SB. Prediction of hip fracture in elderly women: a prospective study. BMJ 1990; 301:638–41.
11. Hans D, Dargent P, Schott AM, et al. Ultrasound parameters predict hip fracture independently of hip bone density: the EPIDOS prospective study. J Bone Miner Res 1995;10(Suppl 1):S169.
12. Graafmans WC, van Lingen A, Oomss ME, Bezemer PD, Lips P. Ultrasound measurements in the calcaneus: precision and its relation with bone mineral density of the heel, hip and lumbar spine. Bone 1996;19:97–100.
13. Jones PRM, Hardman AE, Hudson A, Norgan NG. Influence of brisk walking on the broadband ultrasonic attenuation of the calcaneus in previously sedentary women aged 30–61 years. Calcif Tissue Int 1991;49:112–5.
14. Cartmel B, Moon TE. Comparison of two physical activity questionnaires, with a diary, for assessing physical activity in an elderly population. J Clin Epidemiol 1992;45:877–83.
15. Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenberg RA, Evans WJ. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. JAMA 1994;272:1909–14.
16. Simkin A, Ayalon J, Leichter I. Increased trabecular bone density due to bone-loading exercises in postmenopausal osteoporotic women. Calcif Tissue Int 1987;40:59–63.
17. Chow R, Harrison JE, Notarius C. Effect of two randomised exercise programmes on bone mass of healthy postmenopausal women. BMJ 1987;295:1441–4.
18. Leblanc AD, Schneider VS, Evans HJ, Engelbretson DA, Krebs JM. Bone mineral loss and recovery after 17 weeks of bed rest. J Bone Miner Res 1990;5:843–50.
19. Kannus P, Järvinen M, Sievänen H, Järvinen TAH, Oja P, Vuori I. Reduced bone mineral density in men with a previous femur fracture. J Bone Miner Res 1994;9:1729–36.
20. Voorrips LE, Ravelli ACJ, Dongelmans PCA, Deurenberg P, van Staveren WA. A physical activity questionnaire for the elderly. Med Sci Sports Exerc 1991;23:974–9.
21. Krieg MA, Thiebaud D, Burckhardt P. Quantitative ultrasound of bone in institutionalized elderly women: a cross-sectional and longitudinal study. Osteporos Int 1996;6:189–95.
22. Stegman MR, Heaney RP, Recker RR, Travers-Gustafson D, Leist J. Velocity of ultrasound and its association with fracture history in a rural population. Am J Epidemiol 1994;139:1027–34.
23. Baran DT, Kelly AM, Karellas A, Gionet M, Price M, Leahey D, Steuterman S, McSherry B, Roche J. Ultrasound attenuation of the os calcis in women with osteoporosis and hip fractures. Calcif Tissue Int 1988;43:138–42.
24. Van der Wiel HE, Lips P, Nauta J, Patka P, Haarman HJ, Teule GJ. Loss of bone in the proximal part of the femur following unstable fractures of the leg. J Bone Joint Surg (Am) 1994; 76:230–6.
25. Lilley J, Walters BG, Heath DA, Drolc Z. Comparison and investigation of bone mineral density in opposing femora by dual-energy X-ray absorptiometry. Osteoporos Int 1992;2:274–8.
26. Hutchinson TM, Whalen RT, Cleek TM, Vogel JM, Arnaud SSB. Factors in daily physical activity related to calcaneal mineral density in men. Med Sci Sports Exerc 1995;27:745–50.
27. Pruitt LA, Jackson RD, Bartels RL. Weight-training effects on bone mineral density in early postmenopausal women. J Bone Miner Res 1992;7:179–85.
28. McCartney N, Hicks AL, Martin J, Webber CE. Long-term training in the elderly: effects on dynamic strength, exercise capacity, muscle, and bone. J Gerontol 1995;50A:B97–B104.
29. Prince RL, Smith M, Dick IM, et al. Prevention of postmenopausal osteoporosis: a comparative study of exercise, calcium supplementation, and hormone-replacement therapy. N Engl J Med 1991;325:1189–95.

Received for publication 26 June 1997
Accepted in revised form 1 February 1998