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Original Article

How Hip and Whole-Body Bone Mineral Density Predict Hip Fracture in Elderly Women: The EPIDOS Prospective Study

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Abstract. We conducted a population-based cohort study in 7598 white healthy women, aged 75 years and over, recruited from the voting lists. We measured at baseline bone mineral density (BMD g/cm^2) of the proximal femur (neck, trochanter and Ward's triangle) and the whole body, as well as fat and lean body mass, by dual-energy X-ray absorptiometry (DXA). One hundred and fifty-four women underwent a hip fracture during an average 2 years follow-up. Each standard deviation decrease in BMD increased the risk of hip fracture adjusted for age, weight and centre by 1.9 (95% CL 1.5, 2.3) for the femoral neck, 2.6 times (2.0, 3.3) for the trochanter, 1.8 times (1.4, 2.2) for Ward's triangle, 1.6 times (1.2, 2.0) for the whole body, and 1.3 times (1.0, 1.5) for the fat mass. The areas under the receiver operating characteristic (ROC) curves were not significantly different between trochanter and femoral neck BMD, whereas ROC curves of femoral neck and trochanter BMD were significantly better than those for Ward's triangle and whole-body BMD.

Women who sustained an intertrochanteric fracture were older (84 ± 4.5 years) than women who had a cervical fracture (81 ± 4.5 years) and trochanter BMD seemed to be a stronger predictor of intertrochanteric ([RR = 4.5 (3.1, 6.5)] than cervical fractures ([RR = 1.8 (1.5, 2.3]).

In very elderly women aged 80 years and more, hip BMD was still a significant predictor of hip fracture but the relative risk was significantly lower than in women younger than 80 years.

In the 48% of women who had a femoral neck BMD *T*-score less than –2.5, the relative risk of hip fracture was increased by 3, and the unadjusted incidence of hip fracture was 16.4 per 1000 woman-years compared with 1.1 in the population with a femoral neck BMD *T*-score ⩾–1.

Keywords: Aging; Bone mineral density; Hip fracture; Osteoporosis; Prospective study

Introduction

One of every six white women will have a hip fracture during her lifetime and this event increases significantly the mortality and the morbidity in the elderly population [1,2]. A number of cross-sectional studies have shown that subjects with osteoporotic hip fracture have a lower bone density than controls. The relationship between bone mineral density (BMD) and the risk of hip fracture was confirmed by a prospective study conducted by Cummings et al. [3] that showed that each standard deviation (SD) decrease in femoral neck density, increased the age-adjusted risk of hip fracture 2.6 times (95% CL 1.9, 3.6) in postmenopausal women in general (aged 65 years and more). Two other prospective studies reached the same conclusions [4,5]. Although some recent studies also indicate that bone loss at several

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sites, including the hip, continues into the eighth, ninth and tenth decades [6–10], several others have raised doubts about the ability of bone densitometry to predict fractures in very elderly women [11–13].

The EPIDOS study is original because it focuses on a different population from that in the Study of Osteoporotic Fractures [3]. Our study population is composed of European women and includes a larger number of very old women. The average age is 80.5 years – about a decade older than the other studies – and this age range is especially important when studying hip fractures because the incidence is higher and the consequences are more severe and expensive. Additionally, our study pays attention to the predictive power of whole-body measurements, includes femur region-based analyses, and has sufficient power to allow the comparison of cervical and intertrochanteric fractures.

The first goal of the present study was to define, in a very large population, how BMD measurements at several sites of the proximal femur and the whole body predict hip fracture in elderly women living at home, and whether one site was clearly better than others at predicting hip fractures. As a secondary endpoint we wanted to know whether different patterns were observed between trochanteric and cervical fractures and how the WHO definition of osteoporosis [14] could be used in our elderly population.

Answering these questions should help to establish the appropriate use of bone density measurements in this population for selecting a high-risk group, because prevention of hip fracture is now possible, for example by calcium and vitamin D_3 supplements [15,16] or by other treatments such as inhibitors of bone resorption [17]. Other preventive interventions, such as hip protectors [18], could also be tested in a subset of elderly women exposed to a high risk of hip fracture.

Materials and Methods

Subjects

Seven thousand five hundred and ninety-eight white healthy women, aged 75 years and older were enrolled between April 1992 and December 1993 in an epidemiological multicentre prospective study: the EPIDOS cohort study. They were recruited through the voting lists and several health insurance company registers, from five cities in France (Amiens, Lyon, Montpellier, Paris, Toulouse). Most women were living at home and only 10% were living in nursing homes. Women who had undergone bilateral hip replacement or had a hip fracture previously were excluded. The study was approved by the appropriate committees on human research, and all the women provided written informed consent.

Bone Mineral Density Measurements

The technicians at all the centres were trained together to use standardized procedures for the acquisition and analysis of the scans. An operating manual was available in each centre for further training when needed. Baseline BMD (g/cm^2) and bone mineral content (g/cm) of the proximal femur and the whole body, as well as fat and lean body mass, were measured with Lunar DPX Plus devices (Lunar, Madison, WI). This instrument measures three regions of the hip: femoral neck, trochanter and the Ward's triangle.

A hip phantom was regularly circulating between centres throughout the study to assess the inter-centre reproducibility in vitro of hip BMD measurements. Average phantom BMD values, standard deviation and coefficient of variation for the femoral neck were, respectively: Toulouse 0.979 ± 0.011, 1.11%; Montpellier 0.979 ± 0.012, 1.23%; Amiens 0.984 ± 0.012, 1.20%; Paris 0.977 ± 0.012, 1.27%; Lyon 0.982 ± 0.011, 1.07%; for Ward's triangle: Toulouse 0.861 ± 0.015, 1.75%; Montpellier 0.854 ± 0.014, 1.69%; Amiens 0.868 ± 0.016, 1.79%; Paris 0.858 ± 0.014, 1.66%; Lyon 0.871 ± 0.016, 1.87% and for trochanter region: Toulouse 1.170 ± 0.011, 0.92%; Montpellier 1.170 ± 0.009, 0.80%; Amiens 1.174 ± 0.022, 1.84%; Paris 1.164 ± 0.026, 2.24%; Lyon 1.177 ± 0.011, 0.96%.

The average coefficient of variation in vivo assessed in 40 volunteers aged 40–80 years measured twice was 1.8% (± 0.9) for BMD of the femoral neck, 3.1% (± 1.5) for Ward's triangle, and 2% (± 1.1) for the trochanter. Reproducibility of whole-body measurements was assessed in 5 young volunteers measured 3 times each and the coefficient of variation was 1.1% (± 0.5) for whole body BMD, 5% (± 1.7) for fat mass and 1.5% (± 0.6) for lean mass. The peak bone mass value that we used for femoral neck BMD had been previously measured with a Lunar DPX Plus device in a cohort of 73 healthy French women aged 20–29 years (personal data of Ribot, Fonteille, Pichot, Chaouat, de Vernejoul, Rouat, Defour, Hareng). The peak bone mass is 0.998 and the standard deviation is 0.12. Based on these values, a *T*-score of –1 corresponds to a femoral neck BMD of 0.878 g/cm^2 and *T*-score of –2.5 to 0.698 g/cm^2. This is close to the American reference curve provided by the manufacturer (based on 376 healthy women aged 20–29 years) in which 0.698 g/cm^2 corresponds to a *T*-score of –2.45. To calculate the BMD value corresponding to a *T*-score of –2.5 for other sites, we used American reference values of peak bone mass and standard deviation published by the manufacturer. These values are: BMD Ward's triangle, 0.939 g/cm^2 (± 0.12); BMD trochanter, 0.796 g/cm^2 (± 0.12), BMD whole body, 1.117 g/cm^2 (± 0.08).

Assessment of Hip Fractures

We contacted participants every 4 months by letter or telephone to enquire about fractures. When a patient could not be reached, we obtained information from either a relative or their physician. Only 2% were lost to follow-up. Reported hip fractures were confirmed and classified by a rheumatologist from preoperative radiographs and surgical reports.

Statistical Analysis

The average values of explanatory variables and their standard deviation were calculated for the group of women who sustained a hip fracture and for the group of women who did not. Cumulative incidence was calculated per 1000 woman-years and the confidence interval calculation was based on a Poisson distribution.

We used proportional-hazard analysis to identify the predictive values of the different parameters measured by DXA: hip and whole-body BMD, fat mass and lean mass [19]. Crude relative risks of hip fracture associated with each site of BMD measured were estimated in simple proportional hazard models. Relative risks were standardized to express the risk of fracture associated with a 1 standard deviation decrease (RRsd). The adjusted relative risks were estimated from multivariate proportional hazard models to control for the effect of age and weight because these variables were associated with hip fracture in simple proportional hazard models. Centre was systematically included as an independent variable in the model, although this was not significantly associated with fracture rate, because this is a usual potential confounder. Models were not adjusted for height because this variable was not associated with fracture in simple models. Receiver operating characteristic (ROC) curves were constructed for femoral neck, trochanter, Ward's triangle and whole-body BMD measurements. The areas under the ROC curves were calculated and compared according to the method of Hanley and McNeil [20]. The relative risk of hip fracture associated with a BMD decrease was estimated separately for each type of hip fracture (trochanteric or cervical) compared with women with no hip fracture. We also classified the women into three categories of BMD, according to the definition of osteoporosis proposed by the World Health Organization (WHO). This definition, based on *T*-scores, expresses the number of standard deviations compared with the young normal mean (i.e. $\leqslant -2.5$, > -2.5 and < -1, $\geqslant -1$) [14]. The incidence of hip fracture per 1000 woman-years was calculated for each category defined by the WHO. We also calculated the incidence of hip fracture for two age groups across two femoral neck BMD strata (*T*-score $\leqslant -2.5$ and age $\geqslant$ 80 years; *T*-score $\leqslant -2.5$ and age $<$ 80 years; *T*-score > -2.5 and age $\geqslant$80 years; and *T*-score > -2.5 and age $<$ 80 years).

Analyses were performed with the use of Statistical Analysis Software (SAS, Cary, NC).

Results

Seven thousand five hundred and ninety-eight women were enrolled in the cohort. Baseline characteristics of the 154 women who suffered a hip fracture during the course of the study and of the 7544 women who did not are shown in Table 1. During an average 2 years follow-up (representing 14140 woman-years), 154 women suffered their first non-traumatic hip fracture (79 intertrochanteric fractures, 75 cervical fractures), corresponding to an incidence rate of 10.9 per 1000 woman-years (ICC = 10.8, 11.0). The values of average BMD at each site, stratified by 5-year age strata, are displayed in Table 2.

Crude and adjusted relative risks of hip fracture associated with each measured parameter were estimated. Results are given in Table 3. In simple proportional hazard models, relative risks associated with bone density parameters were all significant, as was the relative risk associated with fat body mass, but lean body mass was not a significant predictor of hip fracture.

In multivariate models, the relative risks associated with bone measurements were still significant and

Table 1. Baseline characteristics of the 7598 women studied to determine prospectively the risk of hip fractures (mean ± SD)

	Women without hip fracture during a 2-year follow-up (*n* = 7544)	Women with hip fracture (*n* = 154)
Age (years)	80.5 (3.8)	82.8 (4.6)
Weight (kg)	59.9 (10.5)	57.5 (10.5)
Height (cm)	153.5 (6.0)	152.6 (6.6)
BMD (g/cm^2)		
Femoral neck	0.72 (0.11)	0.65 (0.10)
Trochanter	0.64 (0.12)	0.56 (0.10)
Ward's triangle	0.58 (0.13)	0.51 (0.12)
Whole-body	0.97 (0.10)	0.92 (0.09)
Fat body mass (kg)	22.0 (7.8)	19.6 (7.5)
Lean body mass (kg)	35.2 (4.0)	34.9 (3.9)

;**Table 2.** Average BMD and standard deviation stratified by 5-year age strata

Age group (years)	No.	BMD (g/cm^2), mean ± SD			
		Femoral neck	Trochanter	Ward's triangle	Whole-body
75–80	3982	0.73 ± 0.11	0.65 ± 0.12	0.60 ± 0.13	0.98 ± 0.09
80–85	2639	0.71 ± 0.11	0.63 ± 0.12	0.58 ± 0.13	0.96 ± 0.09
85–90	841	0.68 ± 0.11	0.61 ± 0.11	0.55 ± 0.13	0.94 ± 0.09
90 +	136	0.67 ± 0.11	0.59 ± 0.11	0.53 ± 0.12	0.92 ± 0.09

Table 3. Relative risk (95% confidence limits) of hip fracture per SD decrease in bone mineral density (BMD), bone mineral content (BMC), fat and lean body mass estimated by simple and multivariate proportional hazards models

	Relative risk (95% CL)	
	Unadjusted	Adjusted[a]
Femoral neck BMD	2.0 (1.7, 2.5)	1.9 (1.5, 2.3)
Ward's triangle BMD	2.0 (1.5, 2.6)	1.8 (1.4, 2.2)
Trochanter BMD	2.4 (1.9, 3.0)	2.6 (2.0, 3.3)
Whole-body BMD	1.7 (1.4, 2.0)	1.6 (1.2, 2.0)
Whole-body BMC	1.7 (1.4, 2.1)	2.0 (1.4, 2.7)
Fat body mass	1.4 (1.1, 1.7)	1.3 (1.0, 1.5)
Lean body mass	1.0 (0.8, 1.3)	1.0 (0.9, 1.2)

[a]Adjusted for age, weight and centre

basically unchanged after adjustment for the potential confounding effect of age, weight and centre. Each SD decrease in bone density increased the risk of hip fracture adjusted for age, weight and centre by 1.9 (95% CL 1.5, 2.3) for the femoral neck, 2.6 times (2.0, 3.3) for the trochanter, 1.8 times (1.4, 2.2) for Ward's triangle, and 1.6 times (1.2, 2.0) for the whole body. Using the bone mineral content instead of the BMD of the whole body was not different: RRsd = 2.0 (1.4, 2.7). Each SD decrease in fat body mass increased the adjusted risk of hip fracture by 1.3 times (1.0, 1.5). No significant increase in the risk of hip fracture was associated with lean body mass

ROC curves were constructed for BMD measurements of femoral neck, trochanter, Ward's triangle and whole body (Fig. 1). The areas under the ROC curves were estimated for each parameter and were compared using a method described by Hanley and McNeil [20]. The areas under the ROC curves and their associated 95% confidence limits are shown in Table 4. The p values in Table 4 indicate whether the difference between the areas under two ROC curves is statistically significant. The difference between the areas under the curves was not statistically significant between trochanter and femoral neck whereas both ROC curves obtained with

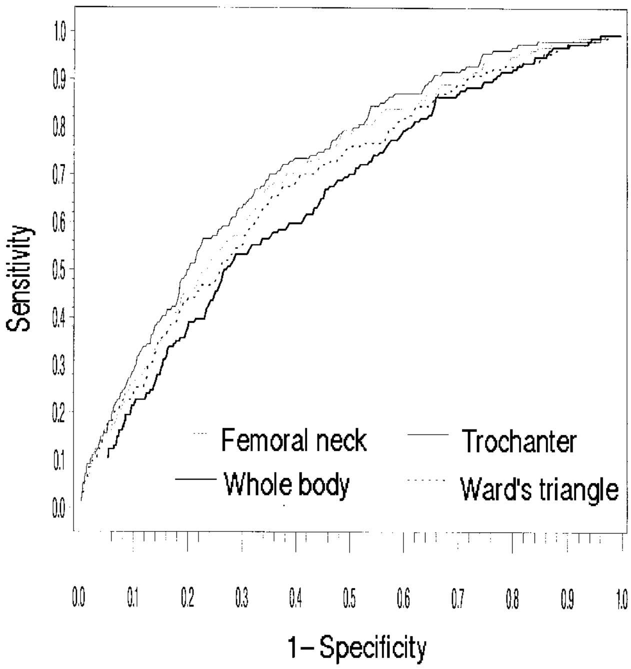

Fig1. ROC curves for femoral neck, trochanter, Ward's triangle and whole-body BMD.

femoral neck and trochanter density were significantly better than Ward's triangle and whole-body bone density.

We analysed trochanteric and cervical fractures separately to assess whether the risk associated with each site showed a different trend according to the type of hip fracture. Table 5 shows the average values of age and bone densitometry in each fracture group and the relative risks standardized for 1 SD. The average age of the women with an intertrochanteric fracture was significantly higher than that of women who sustained a cervical fracture (84 vs 81 years, $p = 0.0005$). Relative risks associated with BMD were similar for the two types of fracture except for the trochanteric region. For this site, the relative risk seemed to be significantly higher for intertrochanteric [RRsd = 4.5 (3.1, 6.5)] than

Table 4. Comparison of areas under ROC curves obtained with measurements of femoral neck, trochanter and whole-body BMD

	Areas under ROC curves (95% CL)	Difference between two ROC curves (95% CL)	p value
Femoral neck	0.70 (0.69, 0.71)	Femoral neck/trochanter 0.022 (–0.007, 0.05)	0.1
Trochanter	0.72 (0.71, 0.73)	Trochanter/whole-body 0.072 (0.034, 0.111)	0.0001
Whole-body	0.65 (0.64, 0.66)	Whole-body/femoral neck 0.047 (0.009, 0.085)	0.02
Ward's triangle	0.68 (0.67, 0.69)	Ward's triangle/femoral neck 0.02 (0.003, 0.035)	0.02
		Ward's triangle/trochanter 0.041 (0.011, 0.071)	0.007
		Ward's triangle/whole-body 0.034 (–0.005, 0.072)	0.09

Table 5. Baseline BMD values (mean ± SD) and standardized relative risks for the intertrochanteric and the cervical fractures group (79 intertrochanteric, 75 cervical)

	Intertrochanteric fractures (n = 79)	Cervical fractures (n = 75)
Mean age (years)	84 (4.5)	81 (4.5)
	Mean BMD (SD)	Mean BMD (SD)
Femoral neck BMD (g/cm^2)	0.63 (0.09)	0.65 (0.10)
Whole-body BMD (g/cm^2)	0.89 (0.10)	0.95 (0.10)
Trochanter BMD (g/cm^2)	0.53 (0.09)	0.57 (0.11)
Ward's triangle BMD (g/cm^2)	0.48 (0.14)	0.53 (0.13)
	Relative risk for 1 SD	Relative risk for 1 SD
Femoral neck BMD (g/cm^2)	2.2 (1.7, 3.0)	2.1 (1.6, 2.7)
Whole-body BMD (g/cm^2)	2.3 (1.8, 3.0)	2.9 (1.3, 6.8)
Trochanter BMD (g/cm^2)	4.5 (3.1, 6.5)	1.8 (1.5, 2.3)
Ward's triangle BMD (g/cm^2)	2.1 (1.7, 2.7)	1.7 (1.3, 2.1)

for cervical fractures [RRsd = 1.8 (1.5, 2.3)]. In the intertrochanteric fracture group, the relative risk associated with the trochanteric density [4.5 (3.1, 6.5)] was significantly higher than that of the other sites [from 2.1 (1.7, 2.7) to 2.3 (1.8, 3.0)], whereas in the cervical fracture group, the relative risk associated with the trochanteric density was not significantly different from the other sites. The decrease of 1 SD in fat body mass increased the risk of cervical fracture by 1.4 (1.1, 1.8) but had no significant influence on the risk of intertrochanteric fracture. Lean body mass did not have any influence on the risk of either type of fracture.

According to the WHO definition of osteoporosis, low bone mass (or osteopenia) is defined as BMD more than 1 SD but less than 2.5 SD below the young normal mean (i.e. T-score < –1 and > –2.5). Women with BMD levels more than 2.5 SD below the young normal mean (i.e. T-score $\leqslant$ –2.5) are considered to have osteoporosis. When we applied this definition of osteoporosis to the femoral neck BMD of our elderly women, only 6.5% were considered as normal whereas 46% were considered as having low bone mass and 48% as osteoporotic, i.e. with a femoral neck BMD lower than 0.698 g/cm^2. Fig. 2 represents the observed unadjusted incidence of hip fracture in our population across the three groups of femoral neck BMD according to the WHO classification. We combined the normal and the low bone mass women into a single group for the following analyses, in an attempt to define a high-risk group consisting of women with femoral neck BMD under T-score –2.5 (the 'osteoporotic' group). Globally, being classified as osteoporotic increased the relative risk of hip fracture 3-fold compared with the combined group of normal and low bone mass women [RR = 3.4 (2.4, 4.9)].

The observed incidence of hip fracture across two age groups ($\geqslant$ 80 years or < 80 years) and two categories of femoral neck BMD (T-score $\leqslant$ –2.5 and T-score > –2.5) expressed per 1000 woman-years, and the corresponding relative risks, are summarized in Table 6. This table shows that the relative risk of hip fracture of the osteoporotic group versus the group of low bone mass and normal women was 4.4 (3.6, 5.5) for women between 75 and 79 years of age compared with 2.5 (2.0,

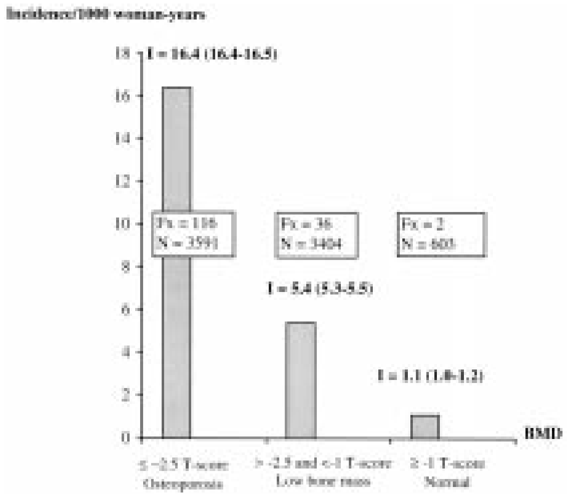

Fig. 2. Hip fracture incidence (I) per 1000 woman-years (95% CL) across three groups of femoral neck BMD. *Fx* number of hip fractures; *N*, number of subjects.

Table 6. Observed incidence rates of hip fracture per 1000 woman-years and relative risk associated with a femoral neck BMD T-score of –2.5 across two age groups

	Incidence rate/1000 woman-years (95% CL)		
	Osteoporotic T-score $\leqslant$ –2.5	Non-osteoporotic T-score > –2.5	Relative risk (95% CL)
< 80 years	12.5 (12.4, 12.6)	2.8 (2.7, 2.9)	4.4 (3.6, 5.5)
$\geqslant$ 80 years	20.0 (19.9, 20.2)	7.6 (7.5, 7.7)	2.5 (2.0, 3.1)

3.1) for women who were 80 years and more. The corresponding excess risks calculated as the difference in fracture rates between women with femoral neck BMD *T*-score below –2.5 in their age group compared with women with a *T*-score above –2.5 in the same group were 9.7 (9.6, 9.8) in women aged 75–79 years and 12.4 (12.3, 12.5) in the older group.

We also analysed the values of BMD in the very oldest group of our population – those over age 85 years. There were 977 women aged 85 years and more. Their average femoral neck BMD was 0.68 g/cm2, trochanter BMD 0.61 g/cm2, Ward's triangle BMD 0.55 g/cm2 and whole-body BMD 0.94 g/cm2. In this age group, 47 hip fractures occurred. The standardized relative risk for 1 SD of femoral neck BMD was 1.6 (1.3, 2.2) in this age group.

We then considered a group of women who had a *T*-score of less than –2.5 at one or more measured site. Among the whole study population of 7598 women, 446 had at least one missing value for BMD at any site; thus the analysis was performed in the 7152 women with no missing values. In this group, 5188 (72.5%) had at least one femoral site and/or whole body BMD *T*-score less than –2.5 and 136 hip fractures occurred. The relative risk of sustaining a hip fracture for women in this group compared with the other group was 4.3 (2.3, 8.0).

Discussion

Despite the results of several cross-sectional studies and prospective studies that show BMD measurements by DXA are significant predictors of hip fracture, these measures are not always recognized by health insurance and policy makers as a necessary tool for screening elderly subjects at risk of hip fracture. Indeed, several reports on the appropriate use of BMD measurements have been published in various countries by either private organizations or governmental agencies, and their conclusions are quite controversial.

There are some unique aspects of our EPIDOS data set. The average age of the subjects is 80.5 years, which is about a decade older than the other studies, and this age range is especially important when studying hip fractures. Most important is the very large number of very old women: 3616 women aged 80 years and more sustained 101 hip fractures and within this subgroup almost 1000 women were more than 85 years old and had 46 hip fractures. Additionally, our study focuses on a European population, which is expected to be different from American women observed in the Study of Osteoporosis [3]. Other original results are provided by the measurements of different femoral sites and of whole-body BMD as well as fat and lean body mass.

Our data confirm that hip BMD is a significant predictor of hip fracture, even in very elderly women. For example, each SD decrease in hip BMD increased the unadjusted fracture risk 2–2.4 times and 1.8–2.6 times after adjustment for age, weight and centre. Our results show that whole-body bone density is also a significant predictor of hip fracture.

Observation of the ROC curves suggested that the trochanteric region could be the best predictor of hip fracture among all the bone density measurements. However, the statistical comparison of the areas under the curves was not significant between femoral neck and trochanter for predicting hip fractures in general. On the contrary, both femoral neck and trochanter bone density were significantly better than Ward's triangle ($p = 0.02$ for femoral neck and $p = 0.007$ for trochanter). and whole-body bone density ($p = 0.02$ for femoral neck and $p = 0.0001$ for trochanter). Whole-body bone density was a significant predictor of hip fracture in regression analyses and this supports the fact that osteoporosis is a generalized disease. However, the ROC curve analyses suggest that the generalized process explains the risk of hip fracture to a lesser extent than does the local bone density.

In very elderly women aged 80 years and more, our results confirm the data published by Hui et al. [12] and by Nevitt et al. [10]. The latter found that the standardized relative risk of hip fracture associated with femoral neck BMD was 2.9 (2.2, 3.9) in women aged 65–79 years and 2.1 (1.4, 3.2) in women aged 80 years and more. The large number of elderly women enrolled in our cohort increases the statistical power of our results and shows that the RR associated with a low femoral neck density is significantly higher for women younger than 80 years than for the more elderly: RRsd = 4.4 (3.6, 5.5) and 2.5 (2.0, 3.1) respectively. Thus in women aged 80 years and more, femoral neck density is a significant predictor of hip fracture; however, this measure has less predictive power than in younger women. We found the same trend for the very old women aged 85 years and more, whose standardized RR associated with femoral neck BMD was 1.6 (1.3, 2.2).

In 1992, a study group convened by the WHO proposed an operational definition of osteoporosis that was designed to be more comprehensive [14]. When we applied this definition to the femoral neck density of our elderly women, only 6.5% were considered as 'normal' whereas 46% were considered as having 'low bone mass' and 48% as 'osteoporotic'. This is consistent with data obtained from an age-stratified sample of the Rochester population extrapolated nationally, where the percentage of women with femoral neck BMD more than 2.5 SD below the mean of normal premenopausal women was 24.5% in the age-group 70–79 years, and 47.5% in the age group $\geqslant$ 80 years [21]. This is also consistent with NHANES data which show that in a population based sample of 218 non-Hispanic white women aged 80+ years, more than 50% had a femoral neck BMD *T*-score lower than –2.5 [22]. Another important issue for the use of WHO definition, or any definition of osteoporosis based on *T*-score, is the choice of peak bone mass value. The reference peak bone mass values currently used were measured recently in young healthy women. The BMD of those young women might be very different from the BMD that current elderly women had when they were young adults. The threshold *T*-score of –2.5 is also influenced by the value of the standard deviation used. In our cohort, the group of women who had at least one BMD measure with a *T*-score of less than –2.5, represented 72% of the study population and their risk of hip fracture was 4.3 times (2.3, 8.0) the risk of women whose BMD measures all had a *T*-score higher than –2.5. However, the percentage of women with a *T*-score less than –2.5 was very heterogeneous across BMD sites: 46.9% for the femoral neck BMD, 70.4% for the trochanter, 30.3% for Ward's triangle and 70.4% for the whole body. This suggests that the osteoporotic process is heterogeneous and/or that peak bone mass and standard deviation values calculated from one population might not be appropriate for all populations. At present there is no evidence that one site is a better predictor and should be preferred. However, the separate analysis of cervical and trochanteric fractures suggested that trochanteric density is a stronger predictor for intertrochanteric fractures [RR = 4.5 (3.1, 6.5)] than for cervical fractures [RR = 1.8 (1.5, 2.3)]. For intertrochanteric fractures, trochanteric BMD was significantly better than the density measured at the other sites. These results are consistent with the fact that the trochanteric region, mainly composed of trabecular bone, mostly reflects trabecular osteoporosis [23]. These results suggest that in addition to femoral neck BMD, trochanteric BMD should be carefully considered, especially in very elderly women who are at higher risk of trochanteric fractures.

The analyses of body mass measurements showed that whole-body fat mass was a significant predictor of hip fracture but that whole-body lean mass was not. The preventive effect of fat mass on the risk of hip fracture is known. Hypotheses for this preventive effect are the increased oestrogen level and/or the local protection against the impact of a fall. Studies on the respective influence of fat and lean mass on BMD are conflicting. Some suggest that fat mass is the major determinant of whole-body BMD [24,25], whereas others suggest that lean mass is the major determinant of whole-body BMD [26]. These studies are mostly cross-sectional and their outcome of interest is the BMD but not the risk of hip fracture. Our study has a prospective design and therefore is less exposed to biases than cross-sectional studies. Additionally, we used hip fracture as outcome, which makes more clinical sense than using BMD. However, the current average follow-up of 2 years might be too short to detect effects that need more time to have a significant clinical influence, especially in elderly women. It is also possible that our method for measuring fat and lean body mass is too global and not precise enough.

The principal interest of this work has been to study a large sample of very elderly women and various BMD sites. Our data suggest that it might not be valid to extrapolate results from 70-year-old women to women older than 80 years. In very elderly women the ability of BMD measurements to predict hip fractures decreases probably because of the increased importance of fall-related factors [27]. However, the incidence of hip fracture increases with age and this explains why having a low femoral neck BMD is associated with the greater excess risk of hip fracture in women aged 80 years and over. The excess risk is a measure that takes into account both the relative risk and the absolute risk of fracture. Even though femoral neck BMD has less predictive power in very old women because of the increased weight of other risk factors, it is still worthwhile measuring femoral neck BMD because of the increasing fracture rate with age. However, the treatment for increasing bone mass should always be associated with other manoeuvres to prevent falls. Additionally, in women aged 80 years and more trochanteric BMD should be taken into account because this is a strong predictor of intertrochanteric fractures, which occur at a later age than cervical fractures.

Appendix. The EPIDOS Study Group

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