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EPIDEMIOLOGY OF VERTEBRAL FRACTURES IN WOMEN

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Vertebral fracture prevalence was assessed in an age-stratified random sample of Rochester, Minnesota women aged 50 years and over. Vertebral fractures, including wedge and concavity as well as compression fractures, were common and increased with age. The estimated incidence of new vertebral fractures also rose with age, reaching 29.6 per 1,000 person-years in women aged ≥85 years. The prevalence of one or more vertebral fractures also increased with declining bone mass, reaching 42% in women with spinal bone mineral density less than 0.6 g/cm² by dual photon absorptiometry. Bone mass and age contributed independently to the risk of vertebral fracture, but "age" may reflect other manifestations of osteoporosis.

cross-sectional studies; osteoporosis; risk

Fractures have been associated with age-related bone loss (i.e., osteoporosis) for over a century (1), and vertebral fractures and osteoporosis have been practically synonymous since the time of Albright et al. (2) in 1941. It is surprising, then, that little is known of the epidemiology of vertebral fractures. To our knowledge, incidence and prevalence rates have not been estimated from evaluations of the entire spine, and the relation of fracture prevalence to age and bone mass has not been quantified in a community setting. These aspects of the epidemiology of vertebral fractures are described in the present report, based on data from a random sample of Rochester, Minnesota women.

MATERIALS AND METHODS

An age-stratified random sample of adult Rochester, Minnesota women (n = 300) was selected with the use of the medical records linkage system of the Rochester Epidemiology Project (3). Since over half of the Rochester population is identified annually in this system and most are seen in any three-year period, the enumerated population (those women seen in 1980 ± 1 year) approximates the underlying population of the community, including both free-living and institutionalized persons. It was necessary to screen 538 residents to enroll the 300 women needed. Thirty-four potential subjects were ineligible for the study (30 could not give informed consent and four were pregnant). Of the remaining 504,

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300 (60 per cent) consented to participate. The proportion of participating subjects by age group ranged from a high of 65–67 per cent among those in each decade of age from 40 to 69 years to a low of 48 per cent among subjects aged 35–39 years. The relatively low response rate was mainly caused by the requirement that subjects agree to be studied at intervals for four or more years following the initial assessment. Only among women aged 70 years and over, where the response rate was 56 per cent, did poor health seem to be an important reason for nonparticipation (4), accounting for one-fifth of all refusals in that group.

Vertebral fractures were assessed with anteroposterior and lateral roentgenograms of the thoracic and lumbar spine obtained at a standard target-to-film distance of 105 cm. Only women aged 50 years or over had roentgenographic studies, and the majority of the analysis deals with these 200 women. Because there is no agreed-on definition of vertebral fractures, we used three different approaches. In the first approach, typically done clinically, the roentgenograms on all 200 subjects were read by one of us (BLR), who was unaware of age or medical history (the clinical reading). Each vertebra from the fourth thoracic to the fifth lumbar was classified as fractured or not. However, subjective clinical readings are not standardized, and reproducibility is poor in some settings (5). Because more objective methods are desirable, we used a second method in which we assessed vertebral fractures by measuring the anterior (h_a), middle (h_m), and posterior (h_p) vertical height of each vertebra to the nearest millimeter on the lateral thoracic and lumbar roentgenograms as is done in some clinical studies (the algorithm assessment). The middle height was the mean of "right" and "left" measurements on each vertebra. In this second method, a fracture was considered to be present if h_p was 15 per cent smaller than the posterior height of either adjacent vertebra (compression fracture) or if the ratio h_a/h_p was 0.85 or less (anterior wedge fracture) or the ratio h_m/h_p was 0.85 or less (concavity fracture) within a vertebra. Finally, because we believe this algorithm assessment overdiagnoses vertebral fractures in cross-sectional studies, we used a third method in which fractures were reassessed using the measured vertebral heights and the algorithm described above after adjustment for normal variations in vertebral shape and size (the "adjusted" algorithm). The adjustment factors (table 1) were based on vertebral measurements in 52 of the women, who did not have clinically evident vertebral fractures on roentgenogram, who were not taking corticosteroids, anticonvulsant medication, thiazide diuretics, vitamin D in pharmacologic doses, nor calcium supplements of more than 500 mg/day, and who were free of any disease known to influence bone metabolism.

Age-specific prevalence rates were calculated for women aged 50 years and over. Smoothed prevalence rates, as well as incidence rates, were estimated from the observed prevalence data by means of the method of Leske et al. (6). Vertebral fractures fit the assumptions of their model: they are not lethal and their manifestations do not resolve. Migration was presumably unaffected by the disorder because most vertebral fractures are unknown to the patient.

We also calculated vertebral fracture prevalence rates for specific levels of spinal bone mineral density. Denominators for these prevalence rates were determined as follows: spinal bone mineral density (expressed in g/cm^2) was measured in the region of the first through fourth lumbar vertebrae with dual photon absorptiometry as previously described (7), and was related to age through a multiple regression model weighted for the age-stratified sampling fractions (8). The model was used to estimate the distribution of bone mineral density values (14 intervals from <0.3 to ≥ 1.5, by 0.1 g/cm^2 intervals) for each of six ages corresponding to the midpoints of six age

TABLE 1

Ratios of posterior (hp), anterior (ha) and middle (hm) vertebral heights in 52 "normal" (see Materials and Methods) Rochester, Minnesota women and adjustment factors used in the "adjusted" algorithm for assessing vertebral fractures*

	i	Posterior/posterior above		Posterior/posterior below		Anterior/posterior		Middle/posterior	
		$(hp_i/hp_{i-1}) \times 100$	Adjustment	$(hp_i/hp_{i+1}) \times 100$	Adjustment	$(ha/hp) \times 100$	Adjustment	$(hm/hp) \times 100$	Adjustment
T4	1			95.30	0.047	96.89	0.0311	95.18	0.0482
T5	2	105.26	−0.0526	96.43	0.0357	95.48	0.0452	94.53	0.0547
T6	3	104.01	−0.0401	97.46	0.0254	93.12	0.0688	94.05	0.0595
T7	4	102.87	−0.0287	97.26	0.0274	92.17	0.0783	93.87	0.0613
T8	5	103.07	−0.0307	96.89	0.0311	93.19	0.0681	93.35	0.0665
T9	6	103.60	−0.0360	95.01	0.0499	94.74	0.0526	93.78	0.0622
T10	7	105.55	−0.0555	90.91	0.0909	96.03	0.0397	94.59	0.0541
T11	8	110.24	−0.1024	93.24	0.0676	93.37	0.0663	92.34	0.0766
T12	9	107.50	−0.0750	96.52	0.0348	94.20	0.0580	92.62	0.0738
L1	10	104.13	−0.0413	98.25	0.0175	97.03	0.0297	94.86	0.0514
L2	11	102.33	−0.0233	98.72	0.0128	101.31	−0.0131	94.24	0.0576
L3	12	101.86	−0.0186	103.61	−0.0361	103.41	−0.0341	96.74	0.0326
L4	13	96.82	0.0318	91.85	−0.0815	107.13	−0.0713	101.08	−0.0108
L5	14	108.87	−0.0887			85.63	−0.1437	90.99	0.0901

* In the "adjusted" algorithm, a compression fracture = $[hp_i + (\text{adjustment} * hp_{i-1}) \leq 0.85\ hp_{i-1}]$ or $[hp_i + (\text{adjustment} * hp_{i+1}); \leq 0.85\ hp_{i+1}]$; an anterior wedge fracture = $[ha_i + (\text{adjustment} * hp_i) \leq 0.85\ hp_i]$; and a concavity fracture = $[hm_i + (\text{adjustment} * hp_i) \leq 0.85\ hp_i]$. Note that anterior and posterior heights are reversed for L_5, where "reverse wedging" is the rule.

strata (35–44 years, ... , ≥85 years). The "smoothed" estimates thus obtained provided more stable data for the tails of the bone density distributions but were otherwise comparable with the normally distributed bone mineral density values actually observed within each age-group. The smoothed age-specific distributions were then multiplied by the number of Rochester women in each age stratum to obtain the number of women in each bone mineral density level in each age group. The resulting age-specific figures were summed across age strata to obtain an estimate of the total number of Rochester women in each bone density interval.

Numerators for calculating bone density-specific vertebral fracture prevalence were determined in the following manner: Smoothed age-specific prevalence rates, based on the "adjusted" algorithm, were used to estimate the total number of Rochester women on January 1, 1980 who had one or more atraumatic vertebral fractures. For this analysis, the five women with isolated vertebral fractures due to severe trauma were excluded. The distribution of spinal bone density in women with vertebral fractures, obtained from the sample, was multiplied by the estimated total number of women with vertebral fractures in the underlying population, to derive an estimate of the number of fracture patients in each bone mineral density interval.

The relative contributions of age and spinal bone mineral density to vertebral fracture risk were assessed in a case-control analysis. The main technique of data analysis was multiple logistic regression, with the conditional likelihood method used as described by Breslow and Day (9).

RESULTS

The distribution of fractures by vertebra is shown in figure 1 and reveals concentrations in the midthoracic area and in the region of transition from thoracic to lumbar vertebrae, regardless of which of the three diagnostic approaches is employed. However, use of the 15 per cent criterion to define a fracture produced an excess of fractures because the systematic increase

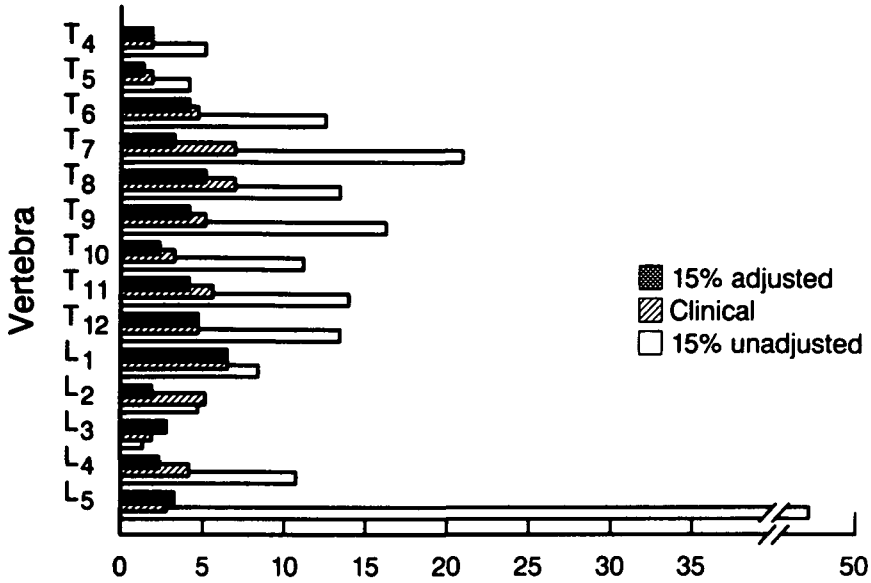

FIGURE 1. Distribution of vertebral fractures by various criteria among Rochester, Minnesota women aged 50 years and over, by vertebra. (Horizontal scale is marked in 5 per cent intervals.)

in vertebral height caudally (figure 2) was not taken into account in defining compression fractures and because the normal shape of vertebrae (shorter anteriorly in the midthoracic area and shorter posteriorly in the lower lumbar region (figure 3)) was not taken into account in classifying wedge and concavity fractures. Overall, 166 (83 per cent) of the 200 women aged 50 years and over were classified as having at least one vertebral fracture with that method. By allowing for systematic variations in vertebral anatomy, on the other hand, the "adjusted" algorithm produced an assessment more consistent with that of an experienced clinical reader, who categorized 56 (28 per cent) of the 200 women as fractured. The "adjusted" algorithm classified 53 (26 per cent) of the 200 women in the radiographic sample as having one or more vertebral fractures. There was imperfect concordance between the latter two methods, however, as they agreed on only 45 of the women (Kappa = 0.76). Because it is not possible at present to determine which method is superior, data from both the clinical reading and the adjusted algorithm assessment were used in most subsequent analyses.

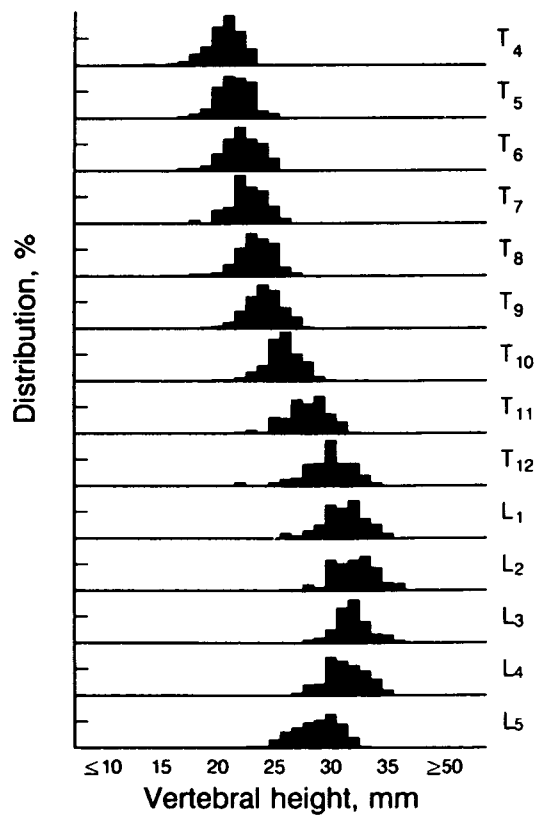

FIGURE 2. Distribution of posterior vertebral heights among Rochester, Minnesota women aged 50 years and over, by vertebra. (Vertical scales are marked in 15 per cent intervals.)

The influence of sex and race on vertebral fracture risk could not be evaluated because all subjects were women and all were white. The effect of aging was first evaluated by determining the age-specific prevalence of vertebral fractures (table 2).

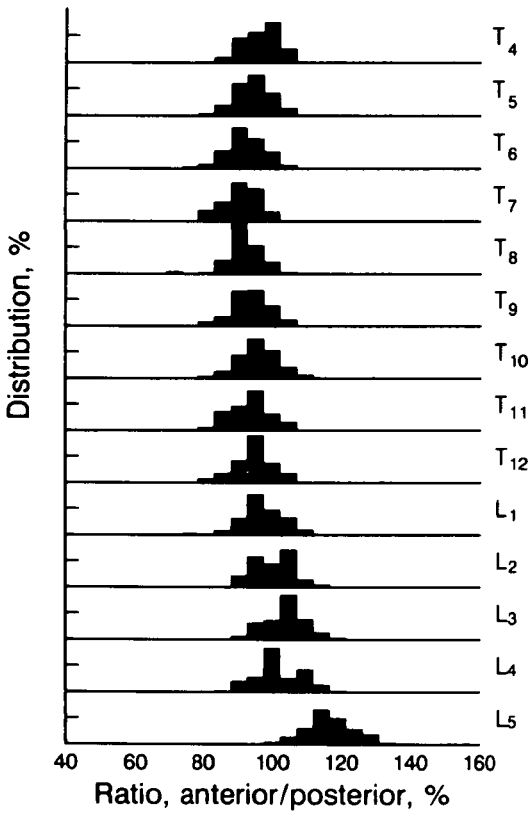

FIGURE 3. Distribution of ratios of anterior to posterior vertebral height among Rochester, Minnesota women aged 50 years and over, by vertebra. (Vertical scales are marked in 15 per cent intervals.)

Calculations were made with and without the five women who had a single vertebral fracture due to a specific episode of severe trauma. In either instance, the prevalence of vertebral fractures rose with age, based on the adjusted algorithm assessment, and the pattern was the same if the clinical readings were used. Prevalence rates reached an estimated 78 per cent among women aged 90 years and over, but that estimate is based on very small numbers.

Since the incidence of vertebral fractures could not be determined in this cross-sectional sample, incidence rates were estimated from smoothed prevalence rates as described in Materials and Methods. These are shown in table 3. When traumatic vertebral fractures were excluded, the smoothed prevalence rose from 6.1 per cent in women aged 50–54 years to 51.7 per cent in women aged 90 years and over. The corresponding incidence of a first vertebral fracture rose from 5.0 per 1,000 person-years in subjects aged 50–54 years to [illegible].6 per 1,000 person-years in women aged 85 years and over. Age-specific incidence rates were somewhat higher when clinically defined vertebral fractures were used in the calculations.

The rise in vertebral fracture incidence and prevalence with aging has been attributed to age-related bone loss. Bone mineral density, an in vivo measure of osteoporosis, declined with age and the overall relation was best described with a cubic model (figure 4). Vertebral fractures were uncommon

TABLE 2

Estimated prevalence of vertebral fractures by age among Rochester, Minnesota women aged 50 years and over. Calculations are made with and without five women with traumatic vertebral fractures

Age group (years)	"Adjusted" algorithm						Clinical reading	
	Including traumatic fractures			Excluding traumatic fractures				
	No. sampled	No. fractured*	Prevalence (%)	No. sampled	No. fractured*	Prevalence (%)	No. fractured*	Prevalence (%)
50–59	46	3	6.5	46	3	6.5	3	6.5
60–69	51	9	17.6	51	9	17.6	9	17.6
70–79	51	14	27.5	50	13	26.0	13	26.0
80–89	43	20	46.5	39	16	41.0	19	48.7
≥90	9	7	77.8	9	7	77.8	7	77.8
Total	200	53	26.5	195	48	24.6	51	26.2

* Number of women with one or more vertebral fractures.

TABLE 3

Smoothed prevalence and estimated incidence of vertebral fractures among Rochester, Minnesota women aged 50 years and over. Calculations are made with and without five women with traumatic vertebral fractures and are shown for both the objective and clinical assessments

Age group (years)	"Adjusted" algorithm				Clinical reading	
	Including traumatic fractures		Excluding traumatic fractures			
	Prevalence*	Incidence†	Prevalence*	Incidence†	Prevalence*	Incidence†
50–54	5.9	5.2	6.1	5.0	5.0	4.9
55–59	8.3	7.3	8.5	6.8	7.3	7.2
60–64	11.7	10.1	11.6	9.3	10.6	10.3
65–69	16.2	13.8	15.7	12.3	15.2	14.4
70–74	21.9	18.2	20.9	16.1	21.3	19.6
75–79	29.0	23.4	27.3	20.5	29.0	25.8
80–84	37.4	28.9	34.7	25.2	38.2	32.3
85–89	46.5	34.0	43.0	29.6	48.3	38.4
≥90	55.9		51.7		58.5	

* Smoothed prevalence (%) of one or more vertebral fractures, determined by the method of Leske et al. (6).
† Estimated incidence per 1,000 person-years, determined from prevalence rates by the method of Leske et al. (6).

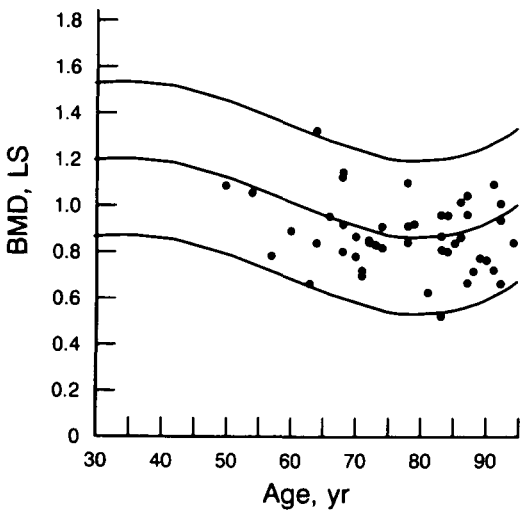

FIGURE 4. Distribution of bone mineral density (BMD) of lumbar spine (LS), by age, among Rochester, Minnesota women. The relation is best described by a cubic model: $\hat{\mu} = 0.517835 + 0.492212 \times 10^{-1} \times \text{age} - 0.105822 \times 10^{-2} \times \text{age}^2 + 0.625726 \times 10^{-5} \times \text{age}^3$; $\hat{\sigma} = 0.158749$, $R^2 = 0.33$. Values for women aged 50 years and over with one or more vertebral fractures are also indicated (●).

until bone mass had fallen considerably from peak levels in young adults: 98 per cent of fracture patients had bone density values below the 50th percentile of persons aged 30 years and 75 per cent had values below the "fracture threshold" (0.97 g/cm^2). Nonetheless, bone mass in women with vertebral fractures was not dramatically lower than in other women of similar age, and the distributions of bone mineral density in the two groups overlapped considerably (figure 5).

Although bone mineral density values did not clearly discriminate between those with and without vertebral fractures, this is not an assessment of fracture risk. Thus, we estimated vertebral fracture prevalence at various levels of spinal bone density for the entire population of Rochester women aged 50 years and over. The total number of such women with one or more vertebral fractures (n = 1,413) was estimated from the smoothed age-specific prevalence rates ("adjusted" algorithm) for atraumatic vertebral fractures. A Gaussian distribution of bone mineral density was then fitted to estimate the number of women with fractures in each bone density interval (table 4). As described in Materials and Methods, the denominator bone mineral density distribution was then estimated for Rochester women generally (table 5). Bone density-specific vertebral fracture prevalence rates were estimated from the numerators in table 4 and the denominators in table 5. These are shown in table 6. Vertebral fracture prevalence increased as bone density declined, reaching levels of about 40 per

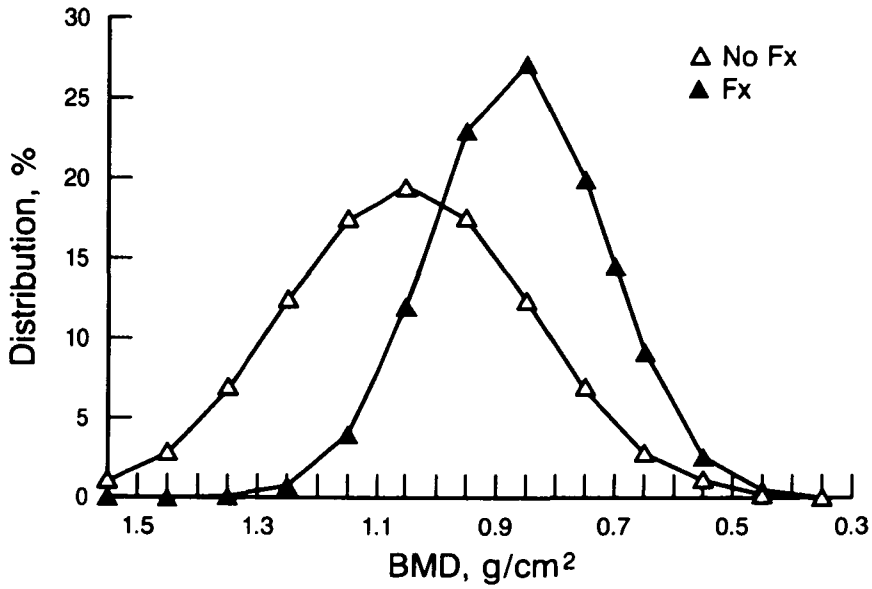

FIGURE 5. Distribution of bone mineral density (BMD) of lumbar spine, by age, among Rochester, Minnesota women aged 50 years and over with (Fx) or without (no Fx) one or more vertebral fractures.

TABLE 4

Distribution of bone mineral density of lumbar spine among women with one or more atraumatic vertebral fractures and expected number with fractures by bone mineral density interval among Rochester, Minnesota women aged 50 years and over on January 1, 1980*

Bone mineral density (g/cm²)	Vertebral fractures	
	Distribution (%)	Expected no.
≥1.30	0.34	4.8
1.20–1.29	1.61	22.7
1.10–1.19	5.83	82.4
1.00–1.09	14.08	199.0
0.90–0.99	22.82	322.4
0.80–0.89	24.79	350.3
0.70–0.79	18.07	255.3
0.60–0.69	8.83	124.8
<0.60	3.63	51.3
Total	100.0	1,413

* Bone mineral density was normally distributed (deviation from Gaussian distribution, $p > 0.85$) among women with atraumatic vertebral fractures ($\hat{\mu} = 0.879167$ and $\hat{\sigma} = 0.155506$) and was not significantly associated with age.

cent among the 6 per cent of women aged 50 years and over who had spinal bone mineral density less than 0.7 g/cm². It should be noted, however, that these prevalence rates relate to people and not individual vertebrae. Among women with a vertebral fracture, the mean number per patient rose from one in women with bone density levels 1.1 g/cm² or greater to over three per person in women with bone density less than 0.8 g/cm².

The relative contributions of spinal bone mineral density and age to the risk of vertebral fracture were assessed in a case-control analysis, considering the 48 women with atraumatic vertebral fractures (defined by the "adjusted" algorithm) as cases and the remaining 147 women as controls; the five women with traumatic vertebral fractures were excluded from this analysis. Results are shown in table 7. Age and bone density were both significant predictors of vertebral fracture status; and, because the correlation between them was modest ($r = -0.28$), their effects were little altered when modeled together. Odds ratios calculated from the beta coefficients indicate that a 10-year increase in age was associated with a 94 per cent increase in risk. A 0.1 g/cm² reduction in bone mineral density (about the amount lost in 10 years on average) was associated with a 44 per cent increase in risk. Findings were virtually identical when

TABLE 5

Distribution of bone mineral density of lumbar spine by age strata for Rochester, Minnesota women aged 50 years and over on January 1, 1980*

Bone mineral density (g/cm²)	Age group (years)										Total No.†
	50–54		55–64		65–74		75–84		85+		
	%	No.	%	No.	%	No.	%	No.	%	No.	
≥1.30	9.36	117.5	3.54	81.8	0.90	18.4	0.46	6.9	0.81	4.9	229.5
1.20–1.29	15.18	190.5	8.42	194.7	3.22	66.2	1.96	29.4	3.00	18.1	498.9
1.10–1.19	23.10	289.9	17.25	399.1	9.30	191.0	6.53	98.2	8.84	53.5	1,031.7
1.00–1.09	23.95	300.6	24.08	557.3	18.25	375.1	14.81	222.7	17.74	107.4	1,563.1
0.90–0.99	16.91	212.2	22.90	530.0	24.41	501.6	22.89	344.2	24.26	146.8	1,734.8
0.80–0.89	8.13	102.0	14.84	343.4	22.24	457.0	24.09	362.4	22.59	136.7	1,401.5
0.70–0.79	2.66	33.4	6.55	151.5	13.80	283.6	17.28	259.8	14.33	86.7	815.0
0.60–0.69	0.59	7.4	1.97	45.5	5.83	119.9	8.44	126.9	6.19	37.4	337.1
<0.60	0.12	1.5	0.46	10.7	2.05	42.2	3.55	53.4	2.24	13.5	121.4
Total	100.0	1,255	100.0	1,314	100.0	2,055	100.0	1,504	100.0	605	7,733

* Based on age-specific means and standard deviation from the cubic model for the age-stratified population sample using Gaussian distributions (normality was verified).

† Estimated bone mineral density-specific population at risk on January 1, 1980.

TABLE 6

Estimated prevalence of atraumatic vertebral fractures by bone mineral density of lumbar spine among Rochester, Minnesota women aged 50 years and over on January 1, 1980

Bone mineral density (g/cm²)	Expected no. with fractures	Estimated population	Prevalence (%)
≥1.30	4.8	229.5	2.1
1.20–1.29	22.7	498.9	4.6
1.10–1.19	82.4	1,031.7	8.0
1.00–1.09	199.0	1,563.1	12.7
0.90–0.99	322.4	1,734.8	18.6
0.80–0.89	350.3	1,401.5	25.0
0.70–0.79	255.3	815.0	31.3
0.60–0.69	124.8	337.1	37.0
<0.60	51.3	121.4	42.3
Total	1,413	7,733	

the clinical assessment of vertebral fractures was used.

DISCUSSION

Vertebral fractures associated with osteoporosis involve the vertebral body and include some combination of compression (collapse of the entire vertebral body), concavity (collapse of the vertebral endplates), or wedging (relative loss of anterior height) (10). When these are *changes* in vertebral shape, they all reflect fracturing (11), and empirical criteria use a 15 per cent reduction in vertebral body height to define a new fracture (12). Shape changes cannot be assessed in a prevalence study, however, and extrapolation of this criterion to the relation among vertebral heights on a single roentgenogram results in an unreasonable number of vertebrae being classified as fractured. Since vertebrae are not all rectangular and the same size, a definition useful for cross-sectional surveys must take into account the systematic variations in vertebral body shape. For this study, we established a preliminary set of adjustments for vertebral size and shape, and developed a new approach to the objective assessment of vertebral fracture prevalence that corresponded fairly well with the interpretations of an experienced clinical reader. The vertebra-specific normative data from this study are comparable to estimates from a series of 150 normal white women aged 34–67 years (13) and from 191 white perimenopausal women (14), although the approach to fracture classification varied from one study to another. However, more work is needed in this area, especially in developing norms for vertebral shape and size based on large numbers of younger women.

Despite these problems with definition,

TABLE 7

Logistic regression analysis of age and bone mineral density of lumbar spine among 195 Rochester, Minnesota women aged 50 years and over with (cases) or without (controls) one or more atraumatic vertebral fractures

Characteristic	Bivariate models		Multiple model	
	β (SE*)	Odds ratio (95% CI†)	β (SE)	Odds ratio (95% CI)
Age (10 years)	0.7332 (0.1620)	2.08 (1.51–2.87)	0.6612 (0.1730)	1.94 (1.37–2.74)
Bone mineral density (0.1 g/cm²)‡	−0.4601 (0.1174)	1.58 (1.25–2.00)	−0.3648 (0.1195)	1.44 (1.13–1.83)
Intercept			−2.5149 (1.7731)	
Model *R*			0.38	

* SE, standard error.

† CI, confidence interval.

‡ At about 1 per cent per year over life, 0.1 g/cm² is the approximate amount of bone lost in 10 years.

it is clear that vertebral fractures are quite common in women and show a rapid rise in prevalence with aging. By means of the smoothed prevalence figures and correction for the age-specific sampling fractions, it is estimated that 18 per cent of women aged 50 years and over in the general population of Rochester have one or more vertebral fractures, and 27 per cent of women aged 65 years and over. Because elderly women who were chronically ill were less likely to have volunteered for the study (4), these estimates could be somewhat conservative. Nonetheless, the high prevalence rates for vertebral fractures seen in this study are very close to estimates from a random sample of Danish women aged 70 years (15) and among selected nursing home residents (16). Some other nonpopulation-based estimates are compatible as well (17, 18). Age-specific rates estimated by Smith and Rizek (19) are lower, but they excluded from their study women who had any condition related to osteoporosis. Prevalence rates based on assessment of small areas of the thoracic (5) or lumbar spine (20) with miniature roentgenograms were only about 2 per cent and 3 per cent, respectively, even among older women. Evaluation of the lower thoracic and lumbar spine among a cohort of women in Hawaii (21) produced prevalence rates nearly as high as those seen in Rochester. In lumbar spine roentgenograms on a random sample of Jerusalem residents (22), on the other hand, the prevalence of vertebral compression fractures reached only 6.8 per cent in women aged 75–84 years, but hip fracture incidence rates were also low in that population compared with Rochester (23).

Because of the gradual and often painless onset of many vertebral fractures, it has proven difficult to measure the incidence of such fractures in the general population. Many vertebral fractures are diagnosed incidentally and their onset cannot be dated, while others are never clinically recognized at all. The only population-based incidence study to date that we know of (24), in fact, appears to describe traumatic vertebral fractures rather than the more typical atraumatic variety common in the general population. Consequently, incidence rates were estimated from the Rochester prevalence data by means of the method of Leske (6). The overall age- and sex-adjusted incidence of vertebral fractures, about 15.4 per 1,000 person-years among white women aged 50 years and over, is about twice the 8 per 1,000 person-years figure derived directly from the study of women in Hawaii (21), where only half of the vertebrae were assessed. Both incidence rates are much higher than the estimated incidence of vertebral fractures nationally in the United States, 1.3 per 1,000 per year (25). However, the latter rate was averaged over blacks as well as whites and over men as well as women. Moreover, the national estimate was restricted to fractures that led to a physician visit or restricted activity, while the Rochester data included wedged and

concave vertebrae that are usually not medically attended.

Because the risk of fracture rises with the level of trauma and with reduction in the ability of bone to withstand the loads imposed (23), epidemiologic patterns of fracture incidence have generally been explained on the basis of age- and sex-specific differences in trauma or, alternatively, on the basis of age- and sex-specific reductions in bone strength. However, vertebral fractures are rarely associated with a specific episode of external trauma (16, 26, 27), and are commonly due instead to loading of the vertebral column during normal daily activities. These loads are surprisingly large (10); when bending the trunk, for example, lumbar vertebrae can be subjected to forces exceeding body weight (28). Moreover, vertebral body strength declines with aging (29), coinciding with loss of trabecular bone (30), and the consequent reduction in strength is disproportionately greater than the reduction in mass (10). Because activities of daily living can generate forces sufficient to fracture vertebrae weakened by osteoporosis (27, 31), fracture risk is closely associated with bone mineral density.

While it is generally presumed that osteoporosis is the main cause of reduced bone strength, there is no clear bimodality in the distribution of bone mineral density in the population, and values overlap widely for age- and sex-matched persons with and without various fractures (7). Women with vertebral fracture generally have lower spinal bone mass than controls (32, 33), and histologic studies (34) and radiographic studies (35, 36) reveal reduced trabecular bone in the vertebral bodies of such women. However, bone mineral density measurements do not clearly discriminate between the two groups, as shown in the present analysis. It is important to note, however, that most of the vertebral fractures in this study represent the wedge deformations of Type II osteoporosis (37). Similarly, in the study of 70-year-old Danish women with vertebral fracture, 80 per cent had vertebral wedging, while only 20 per cent had collapse fractures (15). The reduction in spinal bone mineral density in persons with Type II osteoporosis is not as great, relative to age- and sex-matched peers, as that seen among women with the symptomatic crush fractures of Type I osteoporosis (7, 32).

Nonetheless, vertebral fracture risk does vary with bone mineral density as shown previously for the hip (38) and the distal forearm (39). About 43 per cent of our sample of Rochester women aged 50 years and over had spinal bone mineral density ≥ 1.0 gm/cm^2, and the prevalence of one or more vertebral fractures in this group was only 9 per cent. Even this is an overestimate, however, because it ignores younger women who generally have higher bone mass and few vertebral fractures. The prevalence of vertebral fractures was distinctly greater, 25 per cent, among women with spinal bone mineral density less than 1.0 g/cm^2, and vertebral fracture prevalence increased as spinal bone mineral density declined. The close relation between spinal bone mass and vertebral fracture prevalence has been observed by others (19, 21, 40).

Since bone mass is less in adult women than men at any given age, fracture rates are greater in women, and variation in bone mass may also explain racial differences in vertebral fracture risk (20). Since spinal bone mass declines with age, fracture risk also increases with age. However, the present analysis indicates that bone mineral density, as assessed by dual photon absorptiometry in the lumbar spine, does not entirely account for the age-related increase in fracture prevalence. The residual effect of age may be due to the fact that bone mineral density is not a perfect indicator of bone fragility (41). In addition to the disproportionate mechanical consequences of disrupted trabecular architecture that occur with bone loss (42), there may be biomechanically critical areas of local weakness that are not evident from measures averaged over the entire vertebral body. For example, Genant et al. (43) found a greater

deficit of trabecular than cortical bone in the lumbar spines of women with postmenopausal osteoporosis and vertebral fractures. Moreover, there may be qualitative changes in bone due to altered composition of mineral or matrix (11). These could lead to increased brittleness (11) and microfractures (44–46), perhaps resulting in structural failure of bone even under low loading conditions. Other influences include age-related deterioration of intervertebral discs, that concentrates loads peripherally and potentiates buckling of the vertebral cortex (10), and weakening of abdominal and paravertebral musculature, that increases the loading on the vertebrae (47). Finally, some of the specificity of bone mineral density measurements for vertebral fracture is lost because of artificially high values caused by aortic calcification and hypertrophic changes in the spine (21), which may be more common in women with vertebral fractures (48).

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