Osteoporos Int (1999) 9:206–213

Osteoporosis International

Original Article

Number and Type of Vertebral Deformities: Epidemiological Characteristics and Relation to Back Pain and Height Loss

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Abstract. Vertebral deformity is the classical hallmark of osteoporosis. Three types of vertebral deformity are usually described: crush, wedge and biconcave deformities. However, there are few data concerning the descriptive epidemiology of the individual deformity types, and differences in their underlying pathogenesis and clinical impact remain uncertain. The aim of this study was to compare the epidemiological characteristics of the three types of vertebral deformity and to explore the relationships of the number and type of deformity with back pain and height loss. Age-stratified random samples of men and women aged 50 years and over were recruited from population registers in 30 European centers (EVOS study). Subjects were invited to attend for an interviewer-administered questionnaire and lateral spinal radiographs. The presence, type and number of vertebral deformities was determined using the McCloskey–Kanis algorithm. A total of13 562 men and women were studied; mean age in men was 64.4 years (SD 8.5), and in women 63.8 years (SD 8.5 years). There was evidence of variation in the occurrence of wedge, crush and biconcave deformity by age, sex and vertebral level. Wedge deformities were the most frequent deformity and tended to cluster at the mid-thoracic and thoracolumbar regions of the spine in both men and women. Similar predilection for these sites was observed for crush and to a lesser extent biconcave deformities though this was much less marked than for wedge deformities. In both sexes the frequency of biconcave deformities was higher in the lumbar than the thoracic spine and unlike the other deformity types it did not decline in frequency at lower lumbar vertebral levels. The prevalence of all three types of vertebral deformity increased with age and was more marked in women. There were no important differences in the effect of age on the different deformity types. All types of deformity were associated with height loss, which was greatest for individuals with crush deformity. Back pain was also associated with all types of deformity. Overall, these results do not suggest important differences in pathophysiology between the three deformity types. Biomechanical factors appear to be important in determining their distribution within the spine. All deformity types are linked with adverse outcomes,

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though crush deformities showed greater height loss than the other deformity types.

Keywords: Epidemiology; Osteoporosis; Vertebral deformity; Vertebral osteoporosis

Introduction

Vertebral fracture is one of the important manifestations of osteoporosis. Fractures are usually classified radiologically into one of three types of vertebral deformation: anterior wedge, if there is collapse of the anterior border of the vertebral body; biconcave, if there is collapse of the central portion of the body; and crush, if there is collapse of the entire vertebral body. However, precise criteria for the definition of these different types of deformity have not been established, and detailed information on their epidemiological properties and clinical significance is not available.

Poor inter- and intra-observer reproducibility in defining vertebral fracture based on subjective assessment of spinal radiographs [1,2] has led to the development of methods based on vertebral morphometry [3–6]. Morphometric measurements of anterior, middle and posterior vertebral height provide a quantitative means of distinguishing the three different types of fracture recognized by radiologists, though the term ‘deformity’, rather than fracture, is preferred, in part because not all deformities are due to osteoporotic fracture [7,8].

Our knowledge of the descriptive epidemiology of vertebral deformity, including the influence of age, sex and geography on occurrence, has increased over the last decade, in part due to the application of morphometric methods [9] in large-scale population-based surveys [10,11]. Most of these have focused on the presence or absence of vertebral deformity rather than characterization of the individual deformity types. Previous studies suggest that wedge is the most frequent type of deformity and that there is a peak occurrence of these deformities in the mid-thoracic spine and around the thoraco-lumbar junction [3,12,13]. Less is known about the distribution of biconcave and crush deformities, particularly in men. Such information is potentially important as evidence of variation in occurrence by age, gender and vertebral level might provide clues to pathogenesis.

Vertebral deformities are associated with a variety of adverse health outcomes including back pain, height loss and disability [10,14,15]. Previous studies suggest no important differences in back pain and disability associated with individual deformity types [10,16]; however, these studies have been confined largely to older women.

The European Vertebral Osteoporosis Study is a multicenter radiographic survey of vertebral osteoporosis in men and women. We used data from this study to examine the influence of age and gender on the occurrence of deformity type: crush, wedge and biconcave. We also explored the relationship of deformity type and number with clinical sequelae of vertebral osteoporosis (back pain and height loss).

Subjects and Methods

Thirty-six centers from 19 European countries participated in the study. The design has been described in detail previously [11]. In brief, stratified random sampling was used to recruit approximately equal numbers of men and women from population registers in each center within six 5-year age bands: 50–54, 55–59, 60–64, 65–69, 70–74 and 75+ years. All subjects completed an interviewer-administered questionnaire [17]. This included information on recalled height at age 25 years and history of back pain. Subjects were asked ‘Have you experienced an episode of back pain in the past year?’ (response yes/no). Current height was measured in all subjects. Lateral thoracic and lumbar spine radiographs were obtained using a standard protocol: the radiographs were taken with the patient in the left lateral position, and, for the thoracic films the ‘breathing’ technique was used to allow blurring of overlying ribs and lung detail by motion. The thoracic film was centerd at T7 and the lumbar film at L2. All study radiographs were evaluated morphometrically in Berlin by one of three observers using a translucent digitizer and cursor. Six points were marked on each vertebral body from T4 to L4, and these were used to calculate the anterior (Ha), middle (Hm) and posterior (Hp) heights [4] (Fig. 1). The reproducibility of this method was tested in a random sample of 20 radiographs: the coefficient of variation for the height measurements was 1.6% [18].

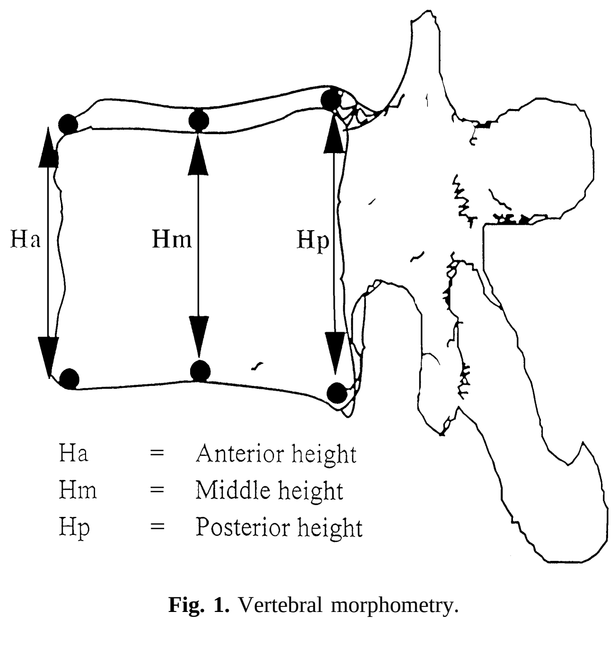

Fig. 1. Vertebral morphometry.

Table 1. Classification of vertebral deformities

Type of deformation	Abnormal ratio(s)	Assignment of deformity
None	None	Normal
Posterior alone	P/P	Normal
Middle alone	M/P	Biconcave
Anterior and posterior	A/P, P/P	Crush
Anterior, middle and posterior	A/P, M/P, P/P	Crush
Anterior alone	A/P	Wedge
Anterior and middle	A/P, M/P	Wedge
Middle and posterior	M/P, P/P	Wedge

A, anterior; M, middle; P, posterior.

Definition of Vertebral Deformity

Vertebral deformity was defined using the McCloskey–Kanis method [5]. Reference ranges for the vertebral height ratios were derived separately by center, gender and vertebral level [11]. A predicted posterior height (H-pred) was calculated for each vertebra from the posterior heights of up to four adjacent vertebrae. Vertebral deformity was defined as present if any of the following criteria were met: (i) Ha/Hp decreased and Ha/H-pred $<$ 3 standard deviations (SD) below reference mean (subsequently referred to as the wedge ratios); (ii) Hm/Hp and Hm/H-pred $<$ 3 SD below reference mean (the biconcave ratios); (iii) Ha/H-pred decreased and Hp/H-pred $<$ 3 SD below reference mean (crush ratios). These criteria may also be used to distinguish wedge, biconcave and crush deformities, respectively. However, several vertebral bodies fulfill criteria for more than one type of deformity and, therefore, we utilized an exclusive definition for the three deformity types, as shown in Table 1.

Analysis

We determined the frequency of each of the three deformity types and the influence of age, sex, and vertebral level on their occurrence. Subjects with multiple vertebral deformities were categorized according to the types of vertebral deformity present: for example, if a subject had two crush deformities and one wedge deformity they would be classified separately as both crush and wedge deformity in the analysis. Logistic regression was used to examine the relationship between type and number of deformities with back pain, after adjusting for age and study center. Height loss was ascertained as the difference between recalled height at age 25 years and measured current height. Test for trend across ordered groups was used to examine the height loss in subjects stratified by type and number of vertebral deformities, after adjustment for age and center.

To determine whether specific types of vertebral deformities tend to cluster within individuals, we studied individuals with two deformities and compared the observed and expected frequencies for the six possible combinations of vertebral deformity types (CC, CB, CW, WW, WB, BB). The expected frequencies were calculated based on the relative frequencies of the three deformity types (C,W,B) in individuals with a single deformity. All analyses were performed using the statistical package STATA [19].

Results

Study Population

In total 17 342 subjects from 36 centers were recruited. Data from five centers that recruited small numbers, and one where there was incomplete questionnaire data, were excluded from the analysis. In total 14 903 subjects aged 50 years and over from the remaining centers had completed radiographic and questionnaire data. In a proportion of subjects (n = 1341, 9%) it was not possible to identify vertebrae at all levels for technical reasons. In these subjects 78% of the vertebrae that were not analyzed were in the upper thoracic region (T4–6). Because one of the aims of the study was to examine the occurrence of vertebral deformity by vertebral level, we restricted the analysis to those 13 562 subjects in whom it was possible to assess all vertebrae (T4–L4). Table 2 shows the age and sex structure of the study sample. In men, the mean age was 64.4 years (SD 8.5 years) and in women 63.8 years (SD 8.5 years). In those subjects who were excluded because not all vertebrae could be assessed, the mean age was slightly higher compared with those studied: in men the mean age was 65.6 years (SD 8.6 years), and in women 65.8 years (SD 9.0 years). As a consequence the prevalence of vertebral deformity was also slightly higher; however, after adjustment for age, the difference disappeared. There were only slight differences in back pain between those excluded and those who were studied (men: 64% vs 67%, women: 81% vs 77%).

Descriptive Epidemiology of Deformity Types

Prevalence. Table 3 presents the frequency distribution of the three types of deformity in men and women. In

Table 2. Age and sex structure of the EVOS study sample

Age group (years)	Men (%)	Women (%)
50–54	1090 (17%)	1349 (19%)
55–59	1195 (19%)	1456 (20%)
60–64	1170 (18%)	1333 (18%)
65–69	1099 (17%)	1191 (17%)
70–74	955 (15%)	1003 (14%)
75+	853 (14%)	868 (12%)
Total	6362 (100%)	7200 (100%)

both sexes, the majority of deformities were wedge, followed by biconcave and crush. Of the 779 men and 875 women with any deformity, a similar proportions had multiple deformities (31%). The proportion of subjects with single and multiple deformities were similar for the three deformity types.

Table 3. Frequency and distribution of type of vertebral deformity in men and women

Deformity type	No. of deformities	Men (n = 6362)	Women (n = 7200)
Wedge deformity	1	411 (6.5%)	461 (6.4%)
	2	81 (1.3%)	94 (1.3%)
	3+	30 (0.5%)	42 (0.6%)
	⩾1	522 (8.2%)	597 (8.3%)
Crush deformity	1	127 (2.0%)	165 (2.3%)
	2	21 (0.3%)	47 (0.7%)
	3+	7 (0.1%)	17 (0.2%)
	⩾1	155 (2.4%)	229 (3.2%)
Biconcave deformity	1	194 (3.1%)	198 (2.8%)
	2	39 (0.6%)	34 (0.5%)
	3+	17 (0.3%)	21 (0.3%)
	⩾1	250 (4.0%)	253 (3.5%)
Any Deformity	1	537 (8.4%)	601 (8.3%)
	2	137 (2.2%)	143 (2.0%)
	3+	105 (1.7%)	131 (1.8%)
	⩾1	779 (12.2%)	875 (12.2%)

Table 4. The frequency distribution of the different combinations of vertebral deformity types by sex

Type of vertebral deformity	No. of subjects with vertebral deformity	
	Men (n = 779)	Women (n = 875)
Wedge only (%)	401 (51%)	444 (51%)
Biconcave only (%)	160 (20%)	147 (17%)
Crush only (%)	84 (11%)	114 (13%)
Wedge and crush (%)	44 (6%)	64 (7%)
Wedge and biconcave (%)	63 (8%)	55 (6%)
Crush and biconcave (%)	13 (2%)	17 (2%)
All three types of deformity (%)	14 (2%)	34 (4%)

Table 4 presents the frequency distribution of the different combinations of vertebral deformity types by sex. The majority of subjects with vertebral deformity (>80%) had only one type of deformity type present.

Anatomical location. Figures 2 and 3 shows the frequency of wedge, crush and biconcave deformities by vertebral level in men and women respectively. The distribution of the three deformity types by vertebral level was broadly similar in men and women. Wedge was the most frequent type of deformity and showed a

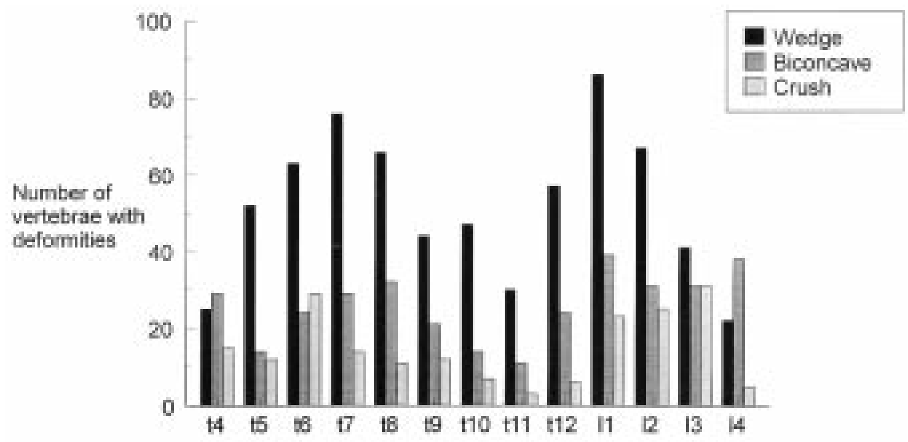

Fig. 2. Number of vertebral deformities by type and vertebral level in men.

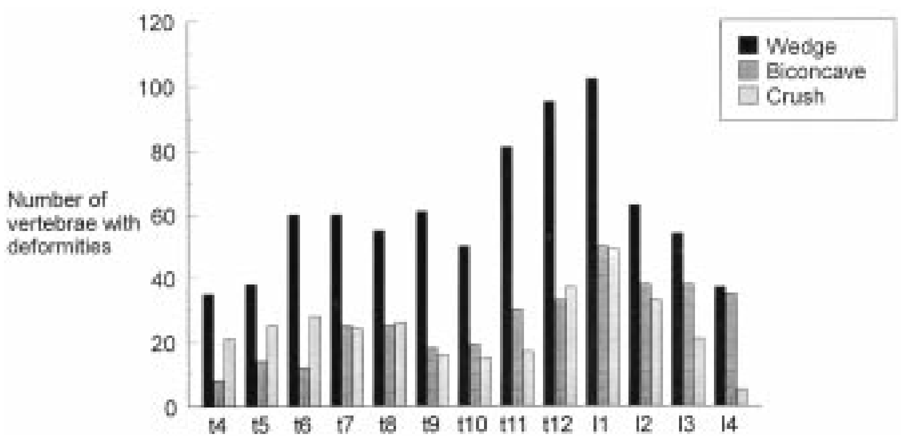

Fig. 3. Number of vertebral deformities by type and vertebral level in women.

Fig. 4. Prevalence of vertebral deformity by type and sex.

Table 5. Clustering of vertebral deformity types in men and women with two vertebral deformities

Cluster type	Men			Women		
	No. of subjects observed with cluster type	No. of subjects expected with cluster type	χ^2 test	No. of subjects observed with cluster type	No. of subjects expected with cluster type	χ^2 test
Wedge/wedge	53	52		52	57	
Biconcave/biconcave	19	9		13	7	
Crush/crush	10	2		20	3	
Wedge/biconcave	27	43		24	39	
Wedge/crush	22	22		26	28	
Crush/biconcave	6	9	χ^2=13.2	8	9	χ^2=18.3
	137	137	p=0.02	143	143	p=0.003

predilection for the mid-thoracic spine (T6–8) and the thoraco-lumbar region (T12–L1). Crush and biconcave deformities were less frequent but also showed predilection for the mid-thoracic and lumbar regions, though the variation by vertebral level was less marked than that for wedge deformities. In both sexes the frequency of biconcave deformities was higher in the lumbar than the thoracic spine, and unlike the other deformity types did not decline in frequency at lower lumbar vertebral levels.

Age. Figure 4 shows the effect of age on the occurrence of the deformity types. Amongst those younger than 65 years the frequency of deformities was greater in men than in women; however, amongst this group the relative distribution of deformity type was similar in men and women, with wedge deformities being most frequent. With increasing age there was an increase in frequency in all three types of deformity, though the increase with age was more marked in women.

Clustering within individuals. There was some evidence of clustering by type amongst individuals with two deformities (chi-squared <0.05). In both sexes, the combination of crush and biconcave deformities, although uncommon, appeared more likely to occur within an individual than would be expected based on the frequency distribution of deformity type in individuals with a single deformity (Table 5).

Relationship with Back Pain and Height Loss

Table 6 shows the relationship between the number and type of vertebral deformity, and risk of reported back pain in the year before interview in men and women. The associations are reported for men and women both together and separately after adjusting for age and center. For each deformity type the association with back pain was assessed using three numerical categories (0, 1, and 2+ deformities). In both sexes, the total number of deformities (‘any’) was significantly associated with a history of back pain (men: p trend <0.01; women p trend <0.01) with no evidence of a threshold. In women, the association was stronger with increasing numbers of wedge deformities, though not for increasing number of crush and biconcave deformities. In men, the

Table 6. Association of back pain in the previous year with type and number of vertebral deformities

Deformity		Men		Women	
Type	No.	OR[a]	95% CI	OR[a]	95% CI
Wedge	0	1.00	–	1.00	–
	1	1.32	1.06–1.63	1.26	1.02–1.57
	2+	1.43	0.96–2.15	1.71	1.14–2.57
	⩾1	1.34	1.10–1.63	1.35	1.11–1.64
p-trend			0.004		0.001
Crush	0	1.00	–	1.00	–
	1	1.22	0.83–1.79	1.44	1.01–2.06
	2+	1.81	0.81–4.05	1.29	0.74-2.26
	⩾1	1.31	0.93–1.9	1.4	1.03–1.9
p-trend			0.07		0.05
Biconcave	0	1.00	–	1.00	–
	1	0.93	0.70–1.27	1.80	1.30–2.50
	2+	2.03	1.14–3.62	1.20	0.66–2.21
	⩾1	1.10	0.84–1.46	1.7	1.23–2.21
p-trend			0.14		0.005
Any	0	1.00	–	1.00	–
	1	1.08	0.89–1.31	1.48	1.22–1.80
	2	1.32	0.91–1.90	1.24	0.86–1.80
	3+	1.94	1.27–2.96	1.70	1.12–2.55
p-trend			0.001		< 0.001

[a]Adjusted for age and study centre.

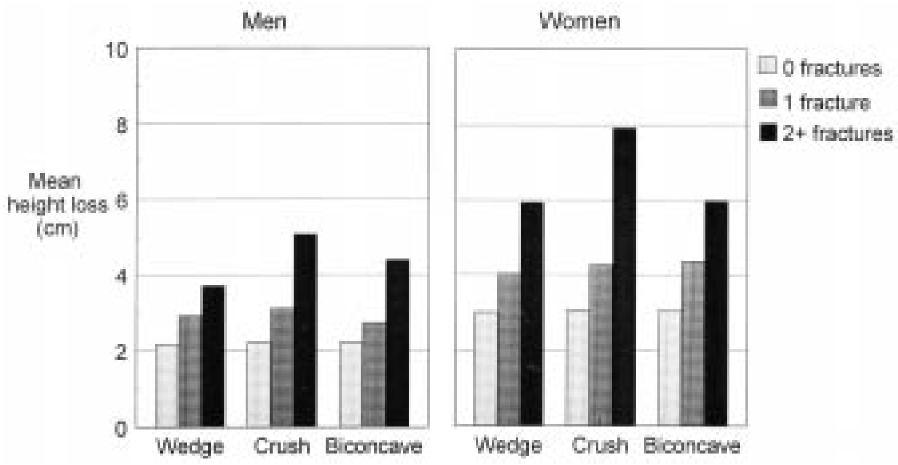

Fig. 5. Mean height loss by type and number of vertebral deformities in men and women.

magnitude of the associations increased with increasing number of deformities, though the trend was significant only for wedge deformities.

Figure 5 shows the average lifetime height loss (recalled height at age 25 years – measured current height) among men and women with increasing numbers of each type of deformity. For each deformity type, the degree of height loss was more marked in women. After age adjustment, there was a strong and statistically significant relationship between the number of vertebral deformities of any type, and height loss (p trend < 0.001). Among both sexes, the height loss was greatest for those with crush deformities, and smallest for those with wedge deformities: in women, the mean height loss for subjects with 2+ wedge deformities (5.9 cm) was significantly less than in those with 2+ crush deformities (7.9 cm; t-test $t = 2.7$, $p = 0.01$), and in men the mean height loss for subjects with 2+ wedge deformities (3.7 cm) was less than that for subjects with 2+ crush deformities (5.1 cm; t-test t = 1.8, $p = 0.08$).

Discussion

In this population-based study of vertebral deformities in European men and women, wedge deformities were the most frequent and showed a predilection for the mid-thoracic and thoraco-lumbar regions of the spine. The distributions of individual deformity types by vertebral level were similar in men and women. All types of vertebral deformity were associated with back pain and height loss, though height loss was more marked in those with compression deformity.

Our study had several strengths: it was large, population-based, included both men and women, and utilized standardized methodology. Nevertheless there are important methodological caveats that influence interpretation of the results. Vertebral deformity was defined using a morphometric approach. While previous studies suggest that such deformities are associated with a reduction in bone mass in men and women [5], other disorders may give rise to alteration in vertebral shape including congenital anomalies, osteoarthrosis and Scheuermann's disease [20]. However, assessments made by trained radiologists appear to be no better than morphometry in identifying fractures linked with reduced bone mass [21,22]. It is possible, nevertheless, that some of our findings in relation to the descriptive epidemiology of the individual deformity types may have been influenced, in part, by the presence of non-osteoporotic deformities.

On the basis of morphometric measurements of vertebral shape, it is possible for a vertebra to have more than one type of deformity (e.g., compression and wedge). In defining type, we used a mutually exclusive definition (Table 1) in which the presence of compression deformity was assessed prior to wedge deformity followed by biconcave deformity. This is the approach explicitly suggested by the McCloskey–Kanis method and similar to that used in previous studies [3,5]. However, the choice is ultimately arbitrary and an alternative approach might produce different results. In a recent analysis of a subset of EVOS subjects for whom bone mineral density (BMD) data were available, deformities that were classified as wedge based on only a reduction in the A/P ratio (Table 1), were less strongly associated with BMD than other deformity types [23]. This suggests that misclassification may be more marked for deformities characterized by a reduction in A/P ratio alone than for the other deformities (including those wedge deformities characterized by other criteria). It is possible that loss of anterior height alone may not be related to osteoporosis, but to other diseases such as osteoarthritis [7], and this may explain the weaker association with BMD. However, the exclusion of these A/P deformities did not alter the results significantly.

The categorization of vertebral deformity type is problematic in subjects with multiple vertebral deformities. We used an approach in which subjects were classified separately by type of vertebral deformity, and a single subject could thus be included in all analyses of all three types (crush/biconcave/wedge). An alternative approach would be to restrict the analysis to subjects with only a single vertebral deformity. However, when the analysis was repeated using this approach, the results of the descriptive epidemiology and clinical impact did not alter significantly.

Our results confirm findings from population-based studies in women that wedge deformities are the most frequent deformity type [3], and that vertebral deformities cluster at the mid-thoracic and thoraco-lumbar regions of the spine [3,13,24,25]. There are few population-based data in men concerning the distribution of deformity types. Cooper et al. [24] reported a similar distribution of deformity types by vertebral level in men and women, with a peak at T8 and L1 in those with symptomatic fracture. In a smaller study, Mann et al. [12] found that wedge deformities tended to cluster in the mid-thoracic region while biconcave deformities were uncommon in the thoracic region. Our findings extend these data. Both biconcave and compression deformities showed similar though less marked variation in occurrence by vertebral level than did wedge deformities. Unlike wedge and crush deformities, biconcave deformities did not decrease in frequency in the lower lumbar spine. Overall the pattern of distribution by vertebral level was similar in men and women.

The increased frequency of vertebral deformities at the mid-thoracic and thoraco-lumbar regions is thought to be due to biomechanical factors [26,27]. The thoracic kyphosis is most pronounced at the mid-thoracic region so that loading in flexion is accentuated. The thoraco-lumbar junction consists of an articulation between the relatively rigid thoracic spine and the freely mobile lumbar segments, maximizing compression stresses. It has been suggested, on theoretical grounds, that endplate deformities occur more frequently in the lumbar spine due to a posterior center of gravity in this region [27]. We found wedge to be the most common deformity type at most vertebral levels. However, the *relative* frequency of wedge compared with biconcave deformity was lowest in the lower lumbar region, providing some support for the latter hypothesis. In EVOS vertebral deformity was more common in younger men than in women [11]. We hypothesized that this may in part be due to an excess of traumatic fractures sustained during occupational or recreational activity. Our findings concerning the relative distribution of deformity types observed in younger men and women suggest that if trauma does indeed play a role in the pathogenesis of deformity in younger men, it does not appear to influence the type of deformity that arises.

A number of population-based studies mainly restricted to women have investigated the relationship between fracture type and clinical symptoms. These suggest no difference in risk of self-reported back pain associated with the different deformity types [10,14]. Our results confirm these findings. All three deformity types were linked with loss of height, though the effect was more marked for compression. Ettinger et al. [10] reported no difference in height in those with crush deformities using a different morphometric approach to defining vertebral deformity [3]. In our study the morphometric approach used to define vertebral deformity [5] had greater specificity for crush deformities because to be defined as a crush deformity, a vertebra needed to fulfill more stringent criteria. It is possible that the reduced misclassification using this approach [28] allowed detection of such differences. In a prospective study, Huang et al. [29] reported no evidence of height loss in those with biconcave deformities, though the findings concerning crush and wedge deformities were similar to those reported here.

In summary, in this cross-sectional population survey we examined epidemiological characteristics of the type of vertebral deformities in men and in women. There are methodological difficulties in the categorization of vertebral deformities morphometrically into clinically recognized types. Biomechanical factors appear to be important in determining their distribution within the spine. All deformity types are linked with adverse outcomes, though crush deformities showed greater height loss than the other deformity types. Our data do not suggest important differences between the types of vertebral deformity in relation to the descriptive epidemiology. Further prospective population-based studies are required to confirm these findings and to enhance our understanding of the natural history of vertebral deformity and the different deformity types, and to examine their relationship with adverse health factors.

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Received for publication 6 February 1998
Accepted in revised form 25 June 1998