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# Vertebral Fracture Assessment Using a Semiquantitative Technique

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## ABSTRACT

**The assessment of vertebral fracture by conventional radiography has been refined and improved using either semiquantitative or quantitative criteria. The inter- and intraobserver variability was determined for a semiquantitative visual approach that we routinely use in clinical studies for assessing prevalent and incident vertebral fractures. In addition, the semiquantitative approach was compared with a quantitative morphometric approach. The incidence and prevalence of vertebral fractures were determined in 57 postmenopausal women (age 65–75 years) by three independent observers. The radiographic basis for fracture definitions and the source of interpretative errors are illustrated. The results show excellent intraobserver agreement and good interobserver agreement for the semiquantitative technique. We conclude that the semiquantitative approach can be applied reliably in vertebral fracture assessment when performed using well-defined criteria.**

## INTRODUCTION

THE ASSESSMENT OF VERTEBRAL FRACTURE on conventional radiographs has been refined by using either semiquantitative or quantitative criteria. Semiquantitative visual approaches based on grading of vertebral fractures have been described.[1,2] Furthermore, various quantitative techniques based on measurements of the vertebral body dimensions have been developed in the last few years.[3-10] This considerable interest in vertebral fracture assessment is linked to the increased interest in osteoporosis research. Osteoporosis is a condition of diminishing bone content and increasing damage to the bone architecture, eventually leading to bone fracture. Vertebral fractures are the most common osteoporotic fractures[11] and are therefore used as outcome variables in osteoporosis prevention and treatment studies.[12]

Limited data are available that show the comparative value of the different approaches for vertebral fracture assessment.[13-15] In this paper, we present a comparison of a semiquantitative approach[2] that is used routinely by us and others in clinical studies[16-21] and a quantitative approach previously described.[15] We assess the inter- and intraobserver reproducibility of the semiquantitative approach. We also illustrate radiographically the basis of fracture definitions and the source of interpretative errors.

## MATERIALS AND METHODS

### *Study population*

The baseline and follow-up (after 2 years) lateral radiographs of the thoracic and lumbar spine were evaluated for 57 postmenopausal women (age 65–75 years) selected from a subset of a large population of women participating in the study of osteoporotic fractures.[22] The study population was enriched in terms of both prevalent and incident fractures, and patients with unreadable films were excluded. All films were taken at a focus-film distancee of 40 inches. The x-ray beam was centered over T8 for the thoracic spine and over L3 for the lumbar spine.

### *Semiquantitative approach*

A visual semiquantitative grading of vertebral fractures was done by two independent observers, one who was considered experienced and the other inexperienced but

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trained to investigate interobserver variance. Vertebrae T4–L4 were graded on visual inspection and without direct vertebral measurement as normal (grade 0), mildly deformed (grade 1, approximately 20–25% reduction in anterior, middle, and/or posterior height and a reduction of area 10–20%), moderately deformed (grade 2, approximately 25–40% reduction in any height and a reduction in area 20–40%), and severely deformed (grade 3, approximately 40% reduction in any height and area). Additionally, a grade 0.5 was given to designate a borderline deformed vertebra. Examples of grades 0, 1, 2, and 3 are shown schematically in Fig. 1 and radiographically in Fig. 2.

For binary fracture versus nonfracture comparison, a vertebral body was considered to be fractured if graded 1 or higher; it was considered normal if graded 0 or 0.5. In addition, a spinal fracture index (SFI) was calculated for each patient by summing the individual vertebral deformity scores and dividing by the number of vertebrae evaluated.

Baseline and follow-up radiographs were viewed simultaneously and in chronologic order. Incident fractures were defined as those vertebral bodies that showed a distinct alteration in morphology resulting in a higher deformity grade on the follow-up radiograph. This implies that prevalent fractures on the baseline could become incident fractures on the follow-up radiograph if the deformity was graded as more severe on the subsequent examination.

The complete set of radiographs was evaluated on two separate occasions by each independent observer to investigate intraobserver reproducibility.

### *Quantitative assessment*

An independent experienced research assistant marked six points per vertebra, defining the anterior $h_a$, posterior $h_p$, and middle $h_m$ vertebral heights. The coordinates of these points were digitized using a back-lit *XY* table. The basic principles are shown in Fig. 3.

In addition, the following ratios were calculated:

Anterior-posterior ratio (APR) = $h_a/h_p$
Middle-posterior ratio (MPR) = $h_m/h_p$
Posterior-posterior adjacent ratio (HPR) = $h_p/h_{pa}$

A prevalent fracture was defined, in accordance with published reports,[1,5,23] as a 15% difference in APR, MPR, or HPR compared to the mean value of a normal population.[9,15] The 15% criterion was chosen because it has

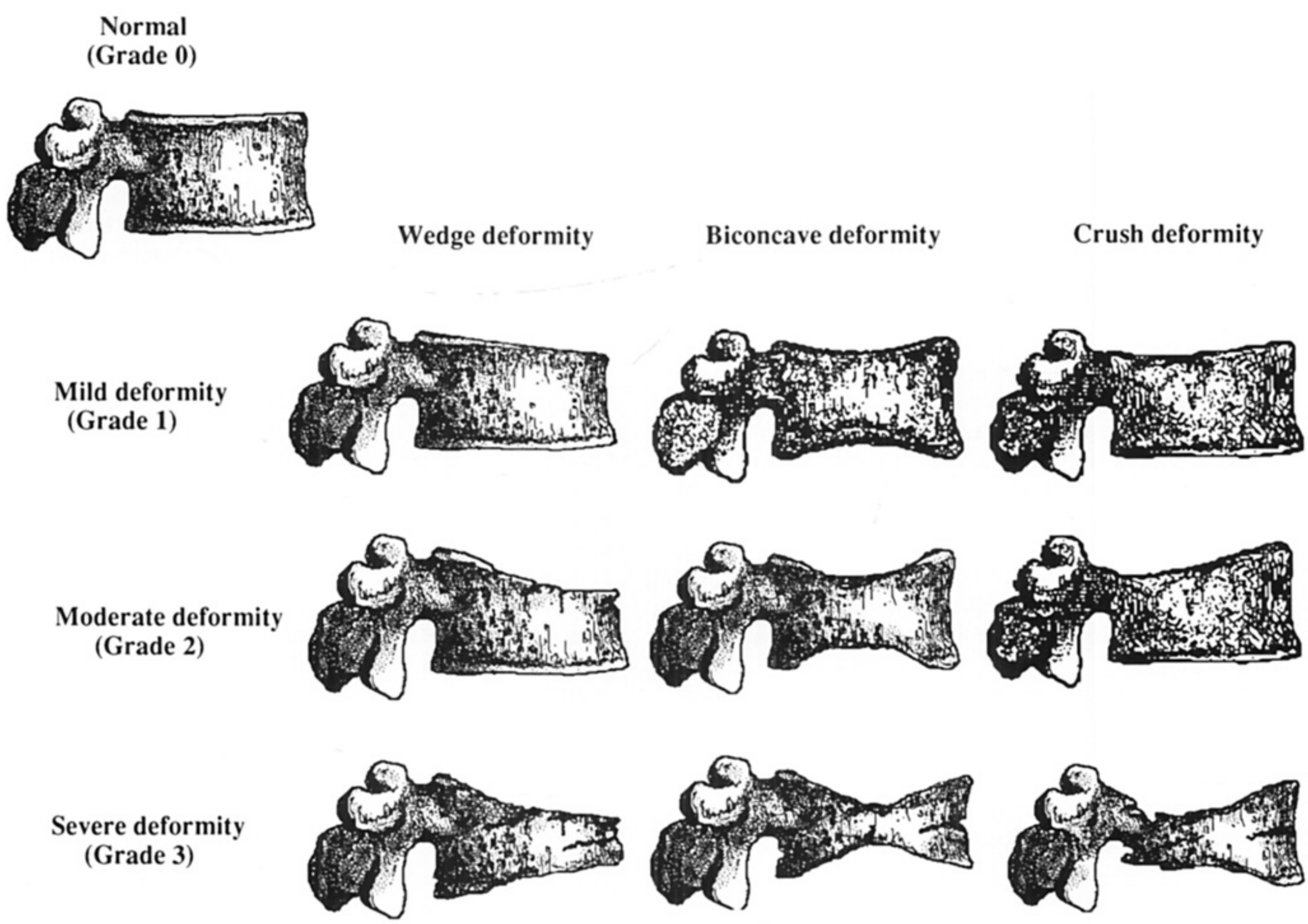


**FIG. 1.** Semiquantitative visual grading of vertebral deformities: Graphic representation.

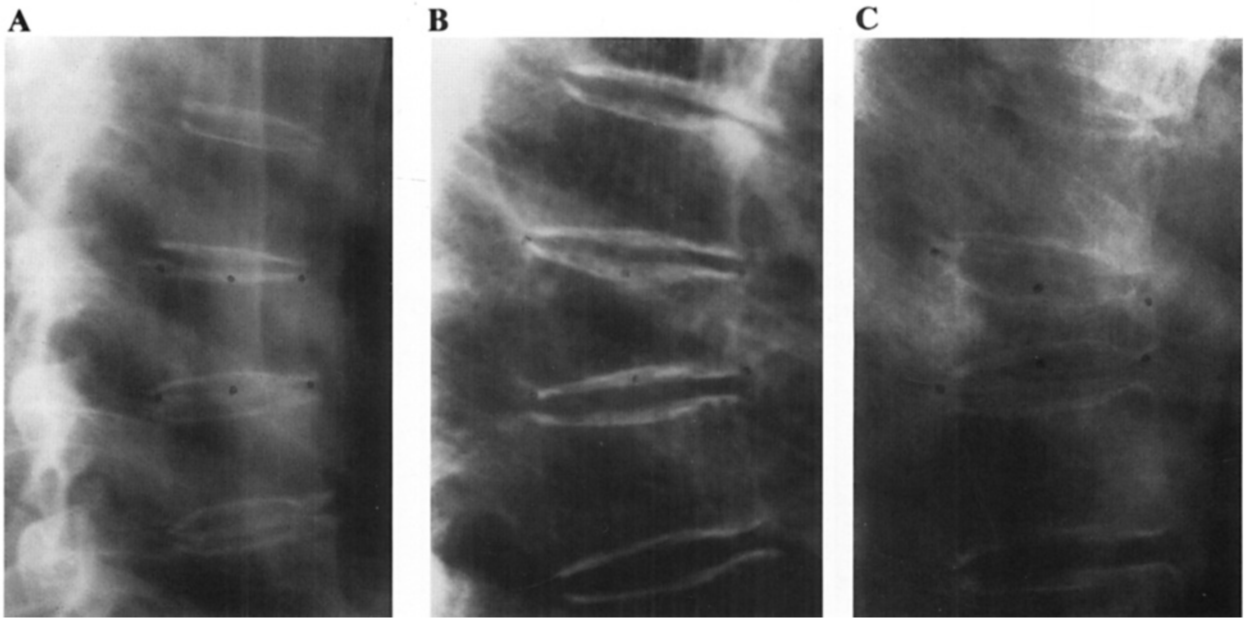

**FIG. 2.** Semi-quantitative visual grading of vertebral deformities: Radiographic representation: (A) Mild, grade 1, wedge fracture of thoracic vertebra. (B) Moderate, grade 2, wedge and end-plate fracture of thoracic vertebra. (C) Severe, grade 3, crush and wedge fracture of thoracic vertebra.

TABLE 1. INTRAOBSERVER VARIABILITY OF SEMIQUANTITATIVE VISUAL ASSESSMENT OF PREVALENT FRACTURES ($N$ = 741)

| | *Prevalence at first reading (%)* | *Prevalence at second reading (%)* | *Percentage agreement* | $\kappa$ | *95% Confidence limits for* $\kappa$ |
|---|---|---|---|---|---|
| Experienced observer | 13.6 | 14.4 | 97 | 0.89 | 0.84–0.94 |
| Inexperienced observer | 14.6 | 15.3 | 93 | 0.73 | 0.66–0.80 |

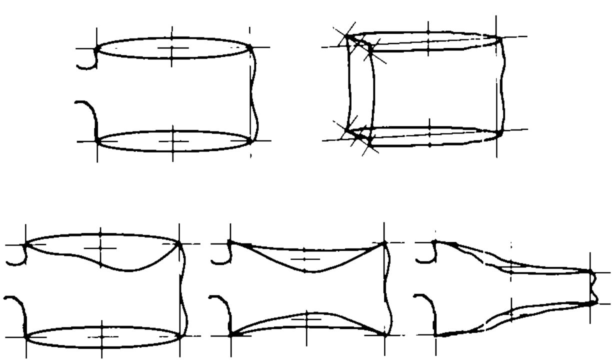

**FIG. 3.** Placement of digitizing points for different projections of the vertebral body.

been widely used before[1,5,23] and because it has been suggested that on visual inspection a trained observer is able to detect an average of 13% reduction in vertebral heights.[12] We also applied another widely used criterion[24,9,15] of three standard deviation difference (3 SD) in height ratios from normative data; however, since the overall comparison with the semiquantitative technique was similar between the 3 SD and 15% criteria, only the latter results are presented.

Incident fractures were defined[23,24] as a decrease in height of more than 15% on the follow-up radiograph (anterior, middle, or posterior height).

### *Statistical analysis*

Results for the different approaches were compared on a per vertebra basis. Agreement between observers and with the quantitative technique was calculated using percentage of agreement and the $\kappa$ statistic:

$$\kappa = (p_0 - p_c)/(1 - p_c)$$

where $p_0$ = the proportion of units in which the judges agreed; and $p_c$ = the proportion of units for which agreement is expected by chance.[25] The results for the spinal fracture index by the two observers were compared using Pearson correlation analysis.

TABLE 2. INTEROBSERVER VARIABILITY OF SEMIQUANTITATIVE AND QUANTITATIVE ASSESSMENT OF PREVALENT FRACTURES ($N$ = 741)

| | *Percentage of agreement* | $\kappa$ | *95% Confidence limits of* $\kappa$ |
|---|---|---|---|
| Experienced versus inexperienced observer | 94 | 0.74 | 0.67–0.81 |
| Experienced observer versus quantitative technique | 93 | 0.68 | 0.59–0.76 |
| Inexperienced observer versus quantitative technique | 92 | 0.65 | 0.56–0.73 |

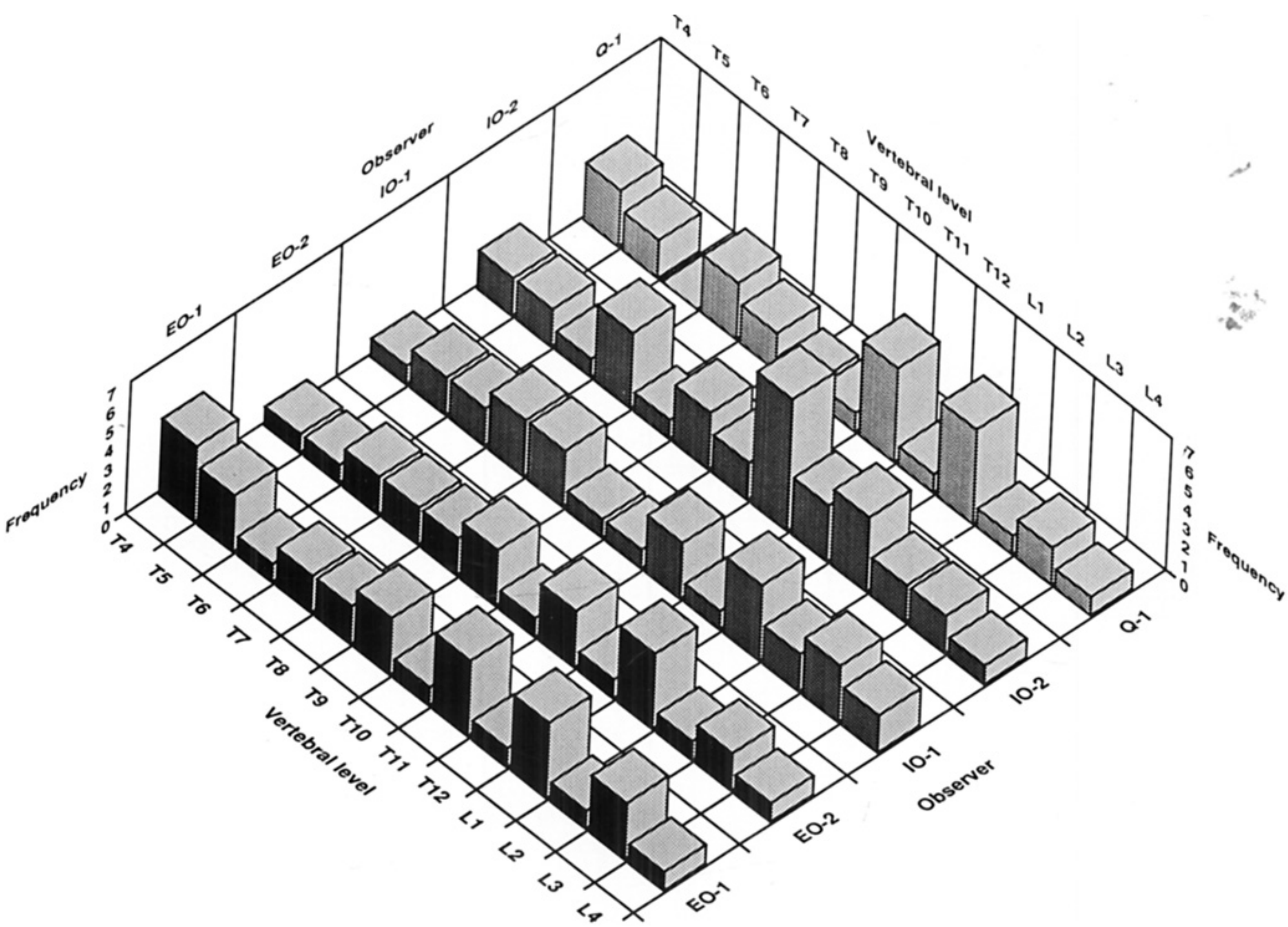


**FIG. 4.** Distribution of prevalent fractures by different observers and methods. IO, semiquantitative assessment by inexperienced observed; EO, semiquantitative assessment by experienced observer; Q1, quantitative assessment.

## RESULTS

### *Intraobserver and interobserver variance for prevalent fractures*

Table 1 shows the fracture prevalence on a per vertebra basis for both observers as assessed on two separate occasions. In 97% of the vertebra the second reading was equal to the first reading for the experienced observer and in 93% for the inexperienced observer. The $\kappa$ statistic showed a $\kappa$ = 0.89 for the experienced observer and $\kappa$ = 0.73 for the inexperienced observer.

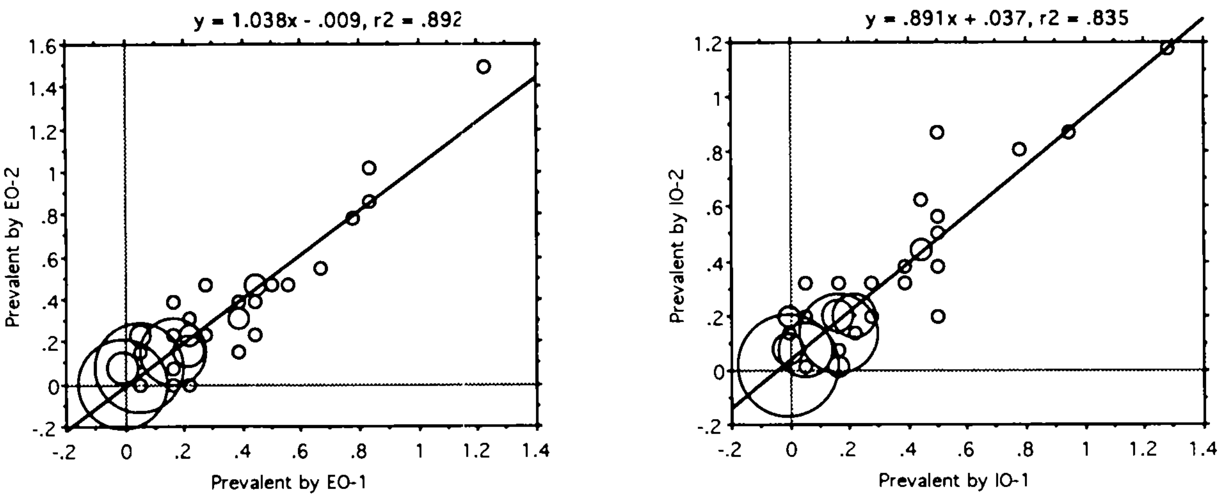


**FIG. 5.** Intraobserver correlations for the spinal fracture index. IO, semiquantitative assessment by inexperienced observer; EO, semiquantitative assessment by experienced observer.

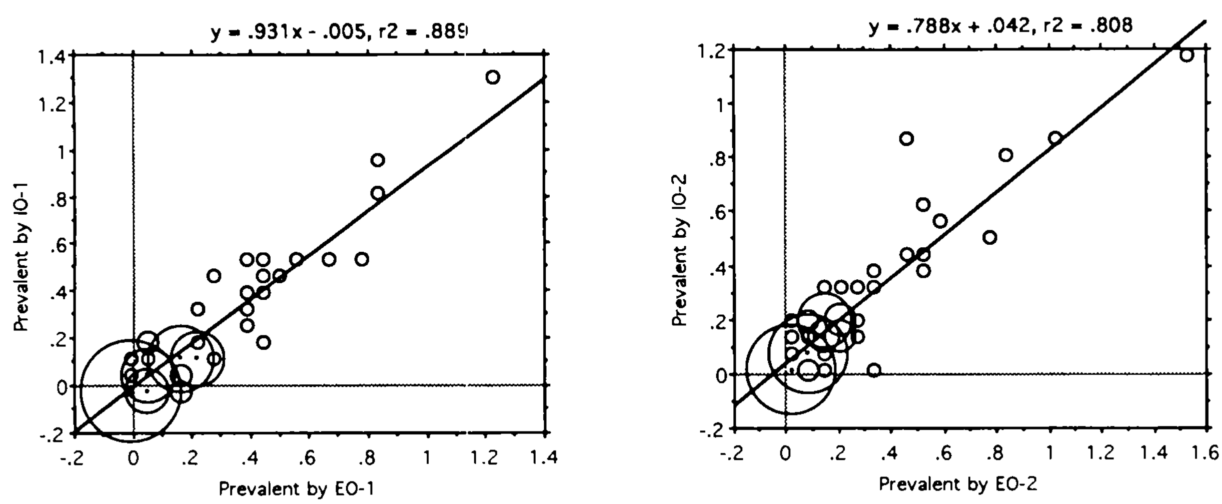


**FIG. 6.** Interobserver correlations for the spinal fracture index. IO, semiquantitative assessment by inexperienced observer; EO, semiquantitative assessment by experienced observer.

Estimated fracture prevalence was 14% (all vertebral bodies) for the experienced observer and 15% for the inexperienced observer. With the quantitative technique the fracture prevalence was 11%.

In Table 2 the interobserver variation for assessment of prevalent fractures is shown. Both observers agreed in 94% ($\kappa = 0.74$) of the cases. The agreement between the experienced observer and the quantitative technique was 93% ($\kappa = 0.68$) and between the inexperienced observer and the quantitative technique 92% ($\kappa = 0.65$).

In Fig. 4 the distribution of the prevalent fractures as detected by the two observers and the quantitative technique is shown. The semiquantitative technique seems to detect more fractures at the midthoracic level than the quantitative technique. As expected, the majority of fractures were detected at the midthoracic and thoracolumbar levels.

In Fig. 5 the correlation for the SFI for both readings for each observer (intraobserver variation) is shown. $R^2$ was 0.892 for the experienced observer and 0.835 for the inexperienced observer.

In Fig. 6 the correlation for the SFI between both ob-

TABLE 3. INTRAOBSERVER VARIABILITY OF SEMIQUANTITATIVE VISUAL ASSESSMENT OF INCIDENT FRACTURES ($N$ = 741)

| | *Incidence at first reading (%)* | *Incidence at second reading (%)* | *Percentage agreement* | $\kappa$ | *95% Confidence limits for* $\kappa$ |
|---|---|---|---|---|---|
| Experienced observer | 3.8 | 4.0 | 99 | 0.93 | 0.86–1.00 |
| Inexperienced observer | 3.2 | 3.8 | 98 | 0.76 | 0.63–0.90 |

TABLE 4. INTEROBSERVER VARIABILITY OF SEMIQUANTITATIVE AND QUANTITATIVE ASSESSMENT OF INCIDENT FRACTURES ($N$ = 741)

| | *Percentage of agreement* | $\kappa$ | *95% Confidence limits of* $\kappa$ |
|---|---|---|---|
| Experienced versus inexperienced observer | 99 | 0.80 | 0.68–0.92 |
| Experienced observer versus quantitative technique | 97 | 0.60 | 0.44–0.77 |
| Inexperienced observer versus quantitative technique | 97 | 0.53 | 0.35–0.72 |

servers is given for both the first and second readings (interobserver variation). $R^2$ for the correlation is 0.889 and 0.808, respectively.

### *Intraobserver and interobserver variance for incident fractures*

Table 3 shows the fracture incidence on a per vertebra basis for both observers as assessed on two separate occasions. In 99% of the vertebra the second reading was the same as the first reading for the experienced observer and in 98% for the inexperienced observer. The $\kappa$ analysis showed a $\kappa = 0.93$ for the experienced observer and $\kappa = 0.76$ for the inexperienced observer.

Estimated fracture incidence was 4% (all vertebral bodies) for the experienced observer and 3-4% for the inexperienced observer. With the quantitative technique the fracture incidence was also 4%.

The interobserver variability is shown in Table 4. Both observers agreed in 99% ($\kappa = 0.80$) of the cases. The agreement between the experienced observer and the quantitative technique was 97% ($\kappa = 0.60$); between the inexperienced observer and the quantitative technique the corresponding figures were 97% ($\kappa = 0.53$).

In Fig. 7 the distribution of incident fractures as detected by the two observers and the quantitative technique is shown.

## DISCUSSION

In this paper we evaluated the inter- and intraobserver variation of a semiquantitative technique for vertebral fracture assessment in a population enriched in both prevalent and incident fractures. We also compared the visual semiquantitative approach with a quantitative morphometric approach for assessing prevalent and incident vertebral fractures.

The percentage agreement between all methods was high. The $\kappa$ analysis showed an excellent to good agreement for the intra- and interobserver variability of the semiquantitative approach. Compared with the experienced and the inexperienced observer, the quantitative approach overall gave a lower fracture prevalence and a similar fracture incidence; however, on a per vertebra basis, there was only modest agreement between the morphometric and visual analyses. The arbitrary 15% deviation in vertebral heights from a normal population used as the definition for prevalent fractures in the quantitative approach seems to be somewhat conservative compared to the semiquantitative assessments of the observers.

Recently, Herss Nielsen and colleagues[26] showed that the inter- and intraobserver agreement for prevalent fractures was also satisfactory when they evaluated another method combining semiquantitative and quantitative criteria. The inter- and intraobserver variation for our semiquantitative technique is also acceptable for the assessment of prevalent and incident fractures. A somewhat better reproducibility for the experienced observer was seen, which is not an unexpected result. The $\kappa$ statistics for our semiquantitative approach are better than those for a purely qualitative assessment of vertebral fractures as reported by Finn Jensen et al.[27] They found $\kappa$ coefficients of 0.62–0.64 for intraobserver variability and 0.47 for interobserver variability using a purely qualitative judgment for prevalent fractures.

The general feeling in the scientific community, con-

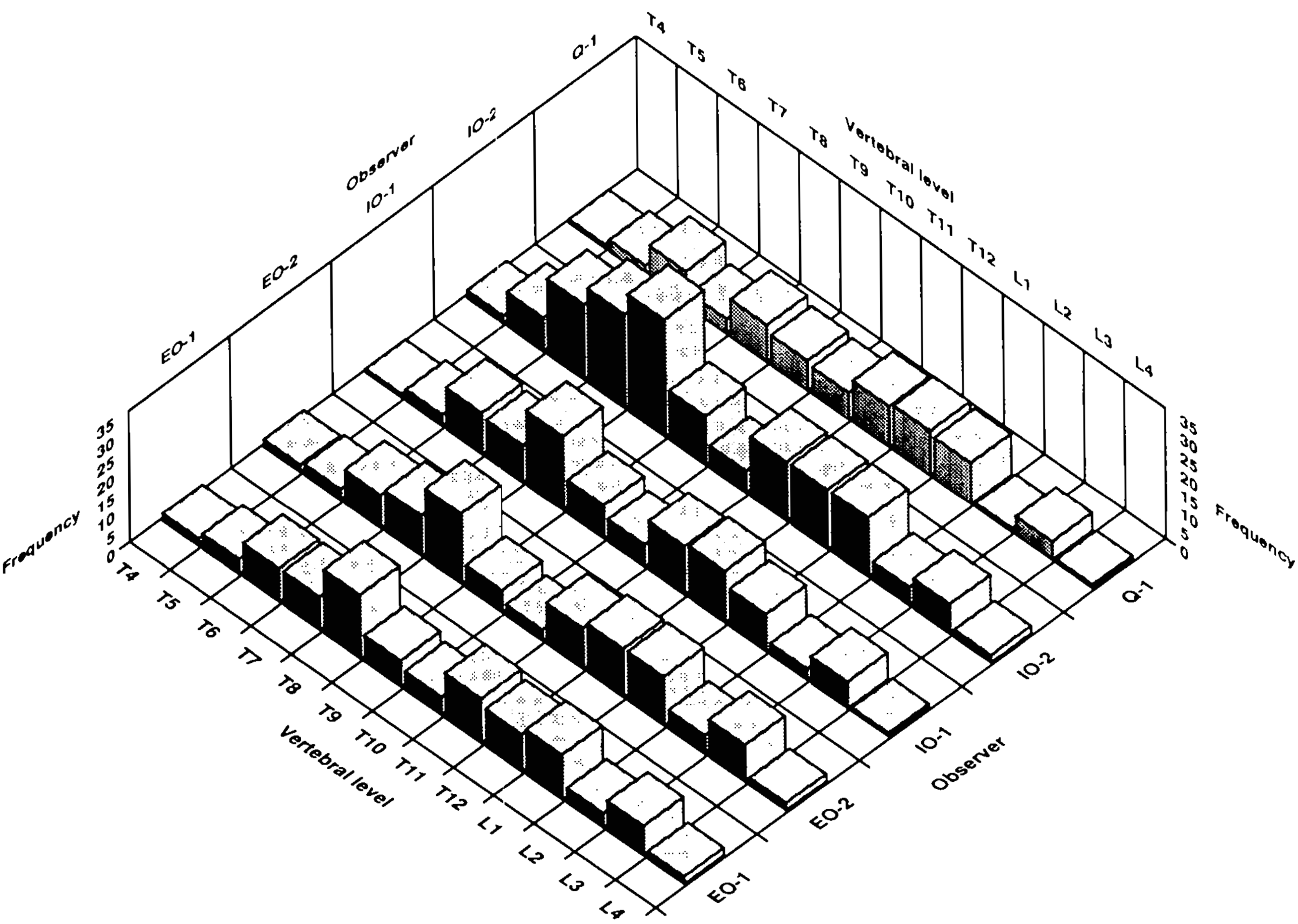


FIG. 7. Distribution of incident fractures by different observers and methods. IO, semiquantitative assessment by inexperienced observer; EO, semiquantitative assessment by experienced observer; Q1, quantitative assessment.

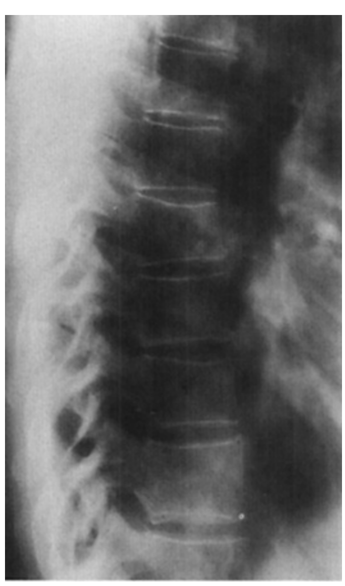

FIG. 8. Lateral thoracic radiograph shows mild fractures of T7 and T9 with deformity and loss of parallelism between end plates.

trasting with the results of our study, is that the interobserver and intraobserver reproducibility for visual methods is a major problem in the assessment of fracture prevalence and incidence in osteoporosis research. Therefore, various quantitative methods for fracture assessment have been developed. These approaches all use vertebral height measurements and calculation of various dimensional ratios. The vertebral heights need to be corrected for variation in human stature (bone size), but both heights and ratios should be adjusted for the natural variations in the anatomic dimensions of bone due to the kyphotic curvature of the thoracic spine and the lordotic curvature of the lumbar spine.

This time-consuming task has been facilitated by digitization techniques and computer-assisted analysis of measurement data. However, varying radiographic quality and parallax distortion of the borders of the vertebral body cause many problems in the placement of the points used for digitization (see also Fig. 3). Furthermore, the placement of the points can be done in several ways.[28] The placement is still a subjective "reading" of the x-ray film. Another problem concerning the quantitative approaches is the cutoff value for identifying vertebral fracture.[10]

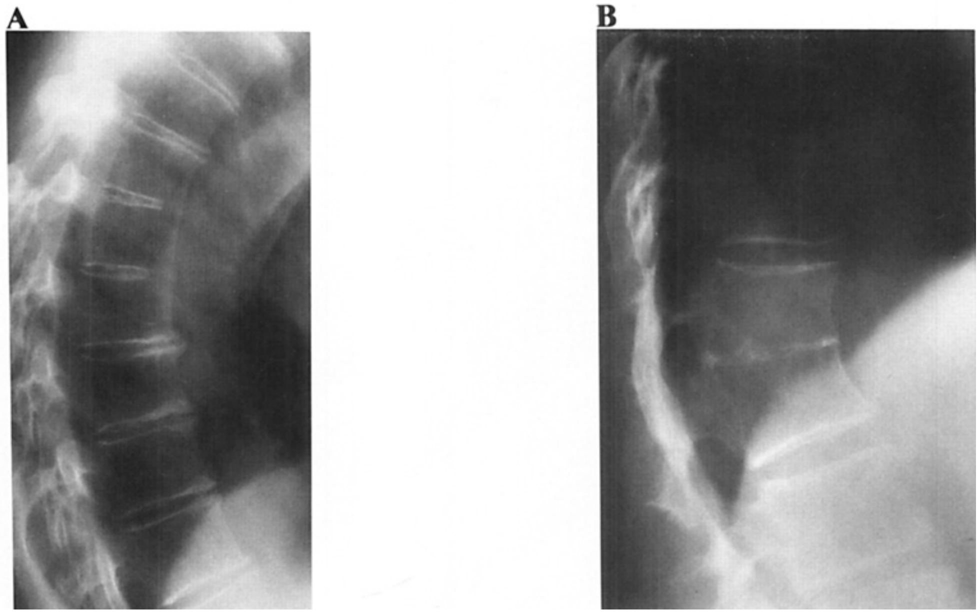


**FIG. 9.** Lateral radiograph shows anomalous fusion of three midthoracic vertebrae (A) and two lower thoracic vertebrae (B).

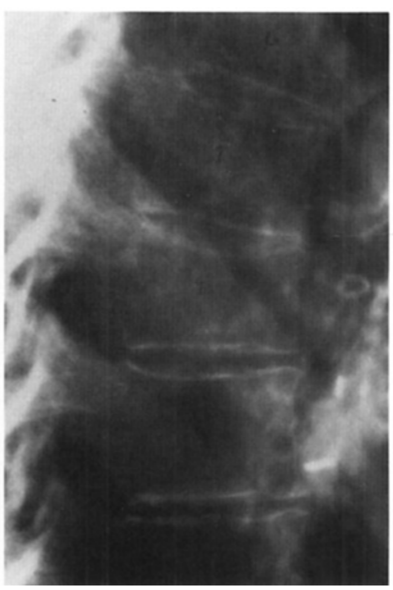

**FIG. 10.** Lateral thoracic radiograph shows a mild fracture of T8 with wedging and end-plate bowing. Although deformed, this vertebral fracture was undetected by quantitative criteria.

**FIG. 11.** Lateral thoracic radiograph shows two adjacent mild vertebral fractures with wedging and end-plate deformity.

Clear differences between the quantitative approaches exist.[14,15] Sauer et al.[14] compared four different quantitative methods and found percentages of agreement ranging from 71 to 86% between the different approaches. We calculated the $\kappa$ statistics from the data as presented in their paper (Table 5 in Ref. 14); the $\kappa$ coefficients generally were of the order of 0.5, ranging from 0.43 to 0.72, indicating only a moderate agreement between the approaches. Additional recent publications have documented substantial discrepancies among the various[15,28–31] quantitative techniques.

In general, the strength of the semiquantitative ap-

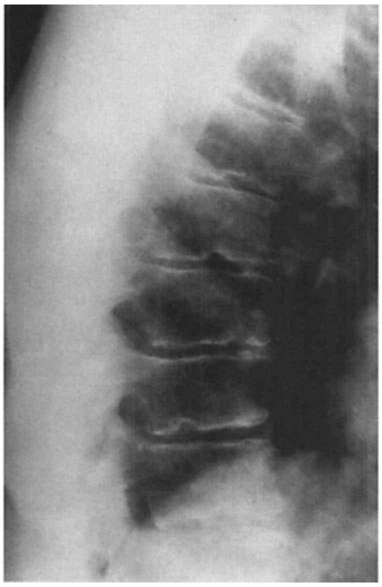

**FIG. 12.** Lateral thoracic radiograph shows multiple Schmorl's nodes and wedge deformities in a characteristic configuration for Scheuermann's disease or juvenile epiphysitis.

**FIG. 13.** Lateral thoracic spine radiograph shows degenerative disk disease and corresponding degenerative remodeling of vertebral bodies.

**FIG. 14.** Lateral lumbar spine radiograph shows obliquity of vertebrae due to scoliosis with related degenerative disk disease simulating a fracture.

proach is that it makes use of the entire spectrum of features that are helpful in identifying fractures (Fig. 8) and separating them from normal or anomalous vertebrae (Fig. 9). Aside from morphometric features, most vertebral fractures are readily distinguished by the presence of end-plate deformities and buckling of cortices, by the lack of parallelism of end plates, and by the loss of vertical continuity of vertebral morphology. Many of these important visual characteristics are not captured when recording six digitization points with the morphometric technique, causing some fractures to go undetected (Fig. 10). Subtle distinctions between a fractured end plate (Fig. 11) and the deformity of Schmorl's nodes (Fig. 12) or the remodeling of the vertebral bodies due to degenerative disk disease (Fig. 13) and scoliosis (Fig. 14) can frequently be made qualitatively by an experienced or trained observer. On the other hand, in the absence of distinct characteristics of fracture, a mild wedge or biconcave deformity could rather arbitrarily be considered normal (see Fig. 2A), anomalous, or fractured by the semiquantitative approach, and in such a case well-defined quantitative criteria could be particularly useful in standardizing detection criteria. Even here, however, with a borderline wedge deformity, small, subjective differences in point placement could result in considerable variance for fracture/nonfracture discrimination on sequential films or even on the same film.

Most incident fractures, similar to prevalent fractures, are readily identifiable and visually apparent on sequential radiographs (Fig. 15). Distinct changes in vertebral configuration as well as size are assessed semiquantitatively. The observed alterations in vertebral morphology for incident fractures are also helpful in understanding and refining the qualitative criteria used for discriminating prevalent fractures. For morphometric analysis, inevitable variation in position and parallax may result in differences in point placement, dictating an incident fracture that can be visually appreciated as simply an alteration in projection (Fig. 16). These sources of false positive or negative interpretation are especially common at a distance from the

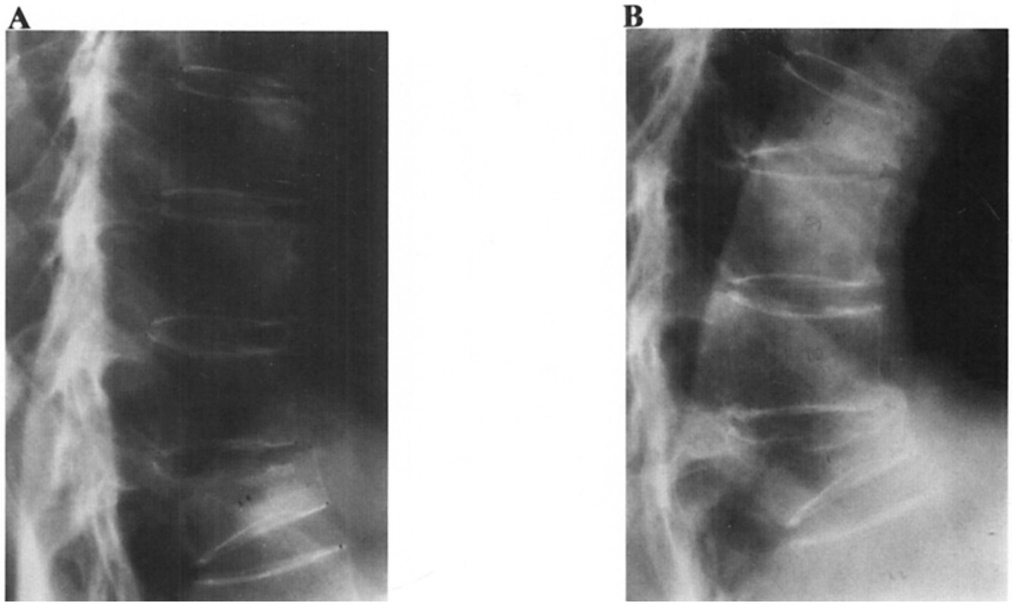


FIG. 15. Lateral thoracic radiographs show obvious severe, prevalent fracture of T11 on baseline study (A) and an obvious incident fracture at T8 on follow-up study (B).

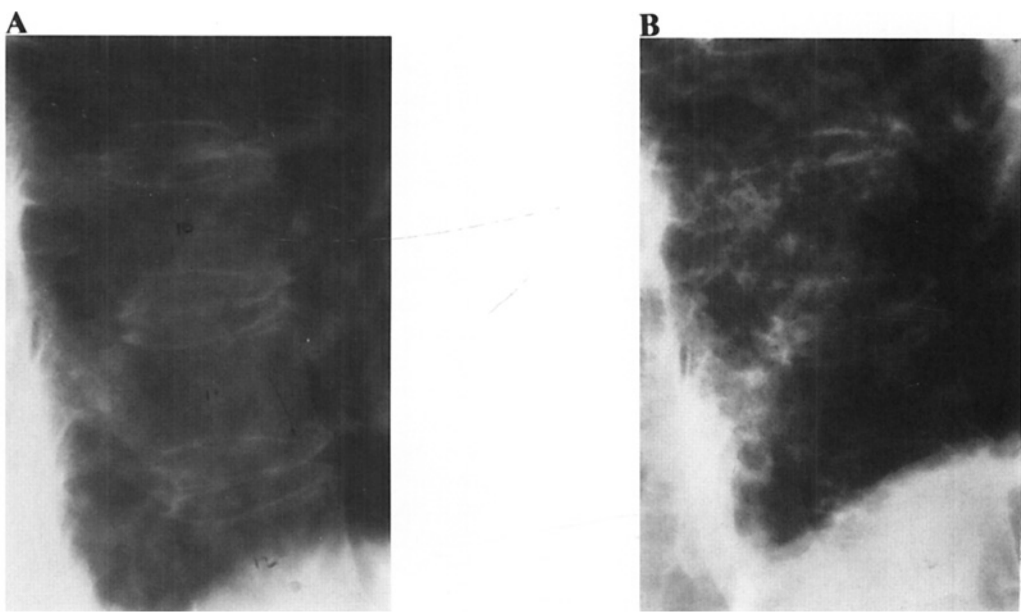


FIG. 16. Lateral thoracic radiographs show obliquity of lower vertebrae on baseline (A) and follow-up studies (B). The poorly visualized vertebral edges resulted in ambiguity of point placement and a false identification of an incident fracture by quantitative criteria (morphometrically).

center of the x-ray beam, where nonorthogonal projection is the rule rather than the exception (Fig. 17).

Intraobserver variability for the semiquantitative approach using defined fracture criteria will depend upon experience and training. However, the same is true for digitizing techniques; an experienced observer is more consistent in the placement of the points for digitization.

The spinal fracture index as derived here gives an overall guide to the severity of osteoporosis in an individual patient. It is useful in studies relating the severity of the dis-

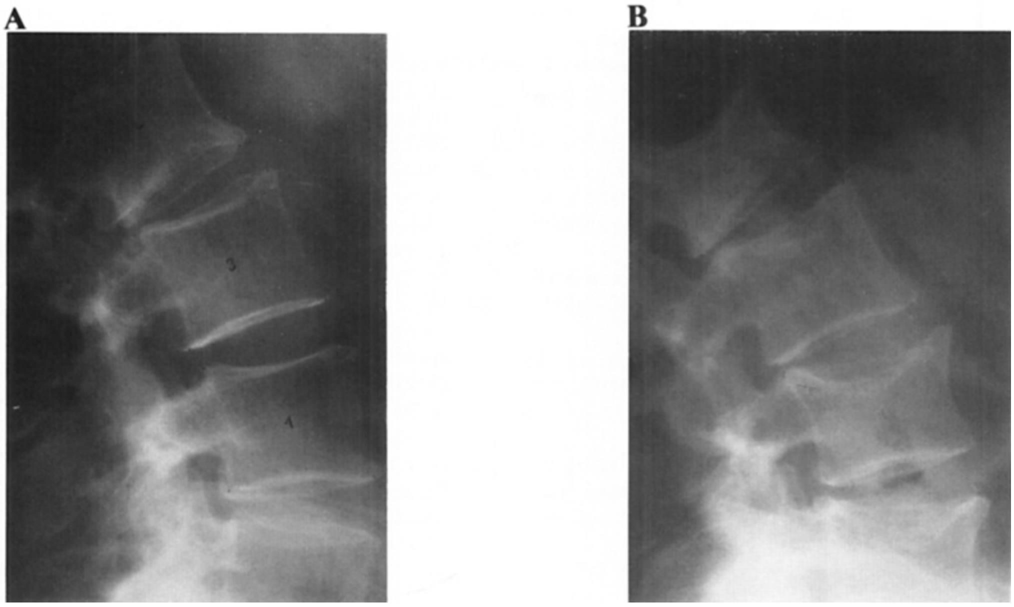

**FIG. 17.** Lateral lumbar thoracic radiograph shows a mild fracture of L2 at baseline (A) detected semiquantitatively only by one observer. Follow-up study (B) shows visually apparent incident fracture at L2 detected by both observers semiquantitatively but not by the observer using quantitative criteria, perhaps as a result of obliquity and variable projections. The incident fracture at L4 was detected by both observers semiquantitatively and by the third observer morphometrically.

ease to other parameters, such as back pain and disability. In this study, we have shown that the inter- and intraobserver variability for the assessment of the SFI is excellent.

Since there is currently no consensus on a gold standard for defining vertebral fracture, it seems advisible to use a combined approach incorporating both visual and morphometric methods for clinical drug trials in osteoporosis. One approach can then be used to detect possible errors and inconsistencies with the other approach, in which case consensus readings might be warranted. As such, the combined approach may provide a measure of quality assurance in the assessment of vertebral fractures, drawing upon the respective strengths of both the semiquantitative and quantitative techniques.

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