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Prevalence and predictors of silent vertebral compression fractures using DXA: a UK Biobank Imaging Study

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Abstract

Objectives Silent vertebral fractures are common but under-recognised. We aimed to estimate the prevalence in an asymptomatic population and to identify demographic and clinical predictors using the UK Biobank data.

Materials and methods DXA spine images from 2446 asymptomatic UK Biobank participants aged 40–79 years were analysed retrospectively. Vertebral fractures were defined as moderate or severe deformities (≥ 25% vertebral height loss). Fractures were identified using an artificial-intelligence-assisted six-point morphometric algorithm with manual correction and radiologist confirmation. Associations with age, sex, bone mineral density (BMD), body mass index (BMI), medication, and back pain were analysed.

Results A total of 2446 participants (mean age 62.0 ± 7.4 years; 1151 men) were analysed. Moderate or severe vertebral fractures were identified in 356 participants (14.6%). Prevalence increased with age, from 9.4% in participants aged 40–49 years to 19.6% in those aged 70–79 years. Fractures were more common in men than women (18.8% vs. 10.8%; adjusted OR 0.51 for women vs. men, 95% CI 0.40–0.66; $p < 0.001$). BMD and most conventional clinical risk factors had limited predictive value.

Conclusions Silent vertebral fractures are common in midlife, frequently occur in individuals with normal bone density, and are more prevalent in men. Conventional clinical risk factors have a limited ability to identify affected individuals.

Key Points

Question *Silent vertebral fractures are frequently overlooked in asymptomatic individuals, and their prevalence and demographic distribution in middle-aged adults are not well-characterised.*

Findings *In a large asymptomatic cohort, vertebral fractures were common, showed male predominance, and were frequently present in individuals without low bone mineral density or recognised clinical risk factors.*

Clinical relevance *Silent vertebral fractures are prevalent in asymptomatic adults and are poorly captured by conventional risk assessment, indicating limitations of current approaches to fracture identification.*

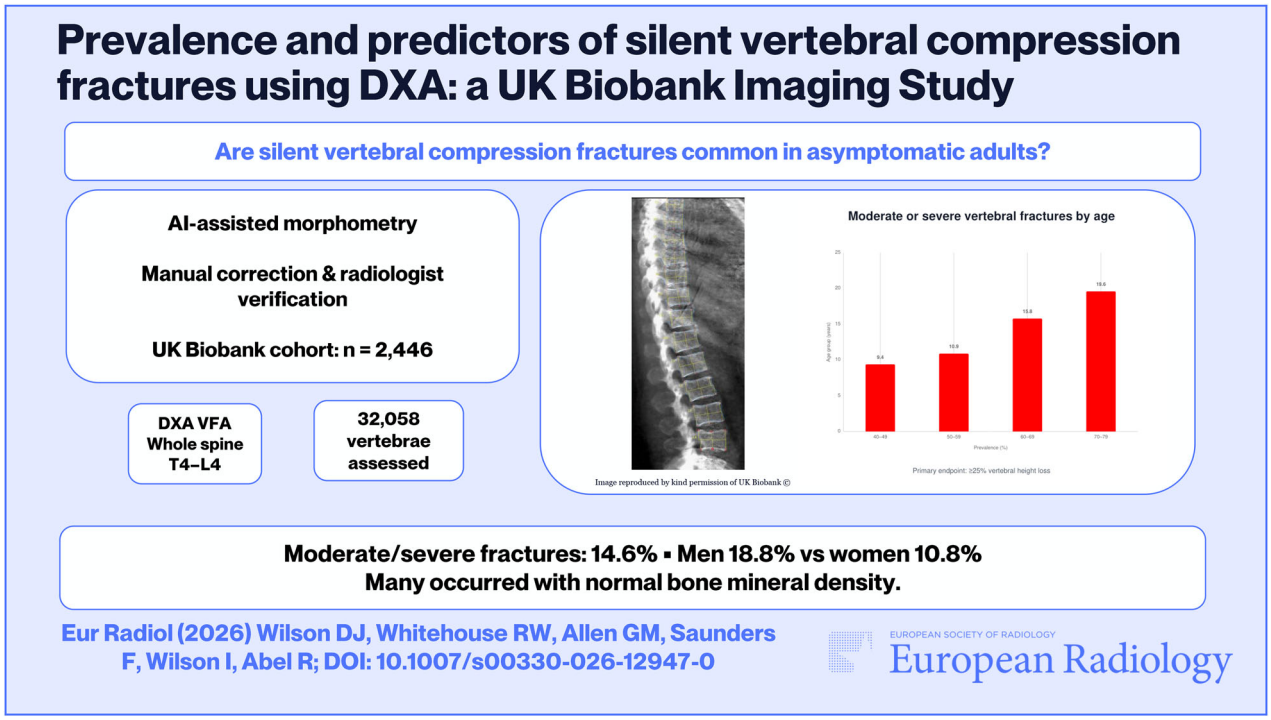
Keywords Vertebral fracture, Dual-energy X-ray absorptiometry, Osteoporosis, Artificial intelligence, Middle aged

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Graphical Abstract



Introduction

Vertebral fractures are common, with around 66,000 symptomatic cases identified annually in England and Wales, many detected incidentally [1, 2]. Many patients are unaware of vertebral fractures and recall no acute back pain or trauma [3]. Asymptomatic fractures are often longstanding and may precede further fractures, leading to height loss, functional decline, and increased mortality. Early medical management may improve outcomes.

Estimates of vertebral fracture prevalence vary widely depending on imaging technique and diagnostic criteria. The European Vertebral Osteoporosis Study reported prevalence rates of 12–20% [4–6]. Other imaging studies have reported values ranging from 4% to over 60%. Previous research also suggested that vertebral fractures occur as frequently in men as in women, challenging traditional assumptions regarding post-menopausal osteoporosis [7–14]. Lower prevalence rates reported in CT-based and radiography-based cohorts likely reflect differences in case selection and diagnostic thresholds, particularly the inclusion of only clinically apparent fractures and the exclusion of mild or asymptomatic deformities [15, 16].

Many individuals with vertebral fractures have normal or osteopenic bone mineral density (BMD), highlighting the limited predictive value of BMD alone [13, 14].

Most research has focused on symptomatic or elderly populations, leaving uncertainty about the prevalence and predictors of silent vertebral fractures in middle-aged adults. Routine DXA imaging provides opportunistic vertebral fracture assessment (VFA).

Using whole-spine DXA imaging from the UK Biobank, we aimed to estimate the prevalence of silent vertebral fractures in asymptomatic adults aged 40–79 years and identify demographic and clinical predictors. AI-assisted morphometry with radiologist verification ensured standardised fracture assessment.

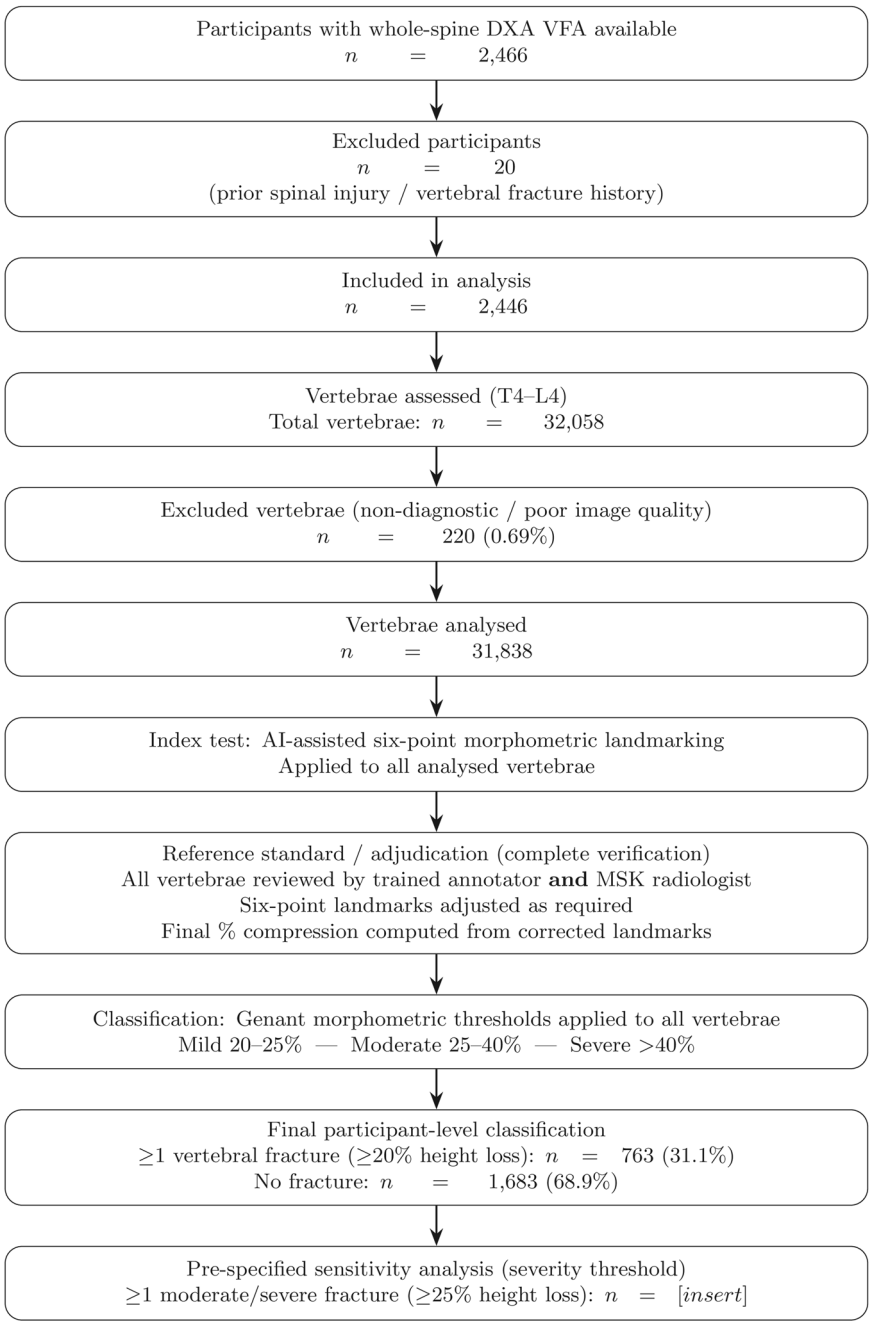
Materials and methods

Study cohort

The UK Biobank is a prospective population study including approximately 500,000 participants, of whom 100,000 underwent whole-spine DXA imaging with VFA. This study was conducted under application 17295.

DXA scans (GE iDXA, software v16.00.158) were acquired at the Stockport Clinical Research Facility between 2014 and 2016, covering vertebral levels T4–L4. Vertebrae with inadequate image quality were excluded.

Available data included demographics, DXA measurements, medical history, and medication records. Participants with prior spinal trauma or known vertebral



Design: complete verification (all participants and all vertebrae received the index test and radiologist-adjudicated assessment).

Fig. 1 Participant flow diagram. Flow of UK Biobank participants through the study, showing inclusion, exclusions, and the final analytic cohort

fractures were excluded. Height and weight were measured using standard procedures, and body mass index (BMI) was calculated. Lumbar spine T-scores were derived automatically by the DXA software.

A total of 2466 participants without prior spinal fracture or trauma were included. Participant selection and exclusions are shown in Fig. 1. Associations between vertebral fracture and participant-level variables (age group, sex, BMI category, BMD category, back pain, and medication use) were analysed. Fracture prevalence was defined as the proportion of participants with at least one fracture. Reference groups were defined a priori.

Vertebral fracture assessment

Fracture detection was performed using an automated six-point morphometric algorithm (IoMSpine, Optasia Medical), which calculates anterior, middle, and posterior vertebral heights and derives standard morphometric ratios. Automated outputs were reviewed by a trained radiographer and manually adjusted where required. All cases were independently verified by an experienced musculoskeletal radiologist, blinded to clinical information. All vertebrae, including those classified as non-fractured, were reviewed.

Fracture severity was categorised as moderate (25–39.9%) or severe (≥ 40%) based on percentage height (Tables 1 and 2).

Interobserver agreement

Two experienced musculoskeletal radiologists independently reviewed 100 randomly selected cases (1287 vertebrae). Vertebral fracture presence and severity were reassessed using morphometric criteria. Interobserver agreement was evaluated using Cohen's weighted kappa and Fleiss' kappa.

Statistical analysis

Statistical analyses were performed in R (version 4.3.0). Categorical variables were compared using χ^2 tests and continuous variables using appropriate parametric or non-parametric methods.

Associations between clinical variables and the presence of vertebral fractures were assessed using multivariable logistic regression to estimate adjusted odds ratios (ORs) with 95% confidence intervals (CIs). Multicollinearity was assessed using variance inflation factors.

Predictive performance was explored using logistic regression and random forest models. Model performance was assessed using sensitivity and specificity. Trend across age groups was assessed using the Cochran–Armitage test.

Results

Cohort characteristics

Of 2466 eligible participants, 20 were excluded due to prior spine injury, leaving 2446 for analysis (mean age 62.0 ± 7.4 years; 1,151 men). Of 32,058 vertebrae assessed from T4–L4, 220 (0.69%) were excluded due to inadequate image quality.

Prevalence of vertebral fractures

Moderate or severe vertebral fractures (≥ 25% height loss) were identified in 356 participants (14.6%). Prevalence increased with age from 9.4% in those aged 40–49 years to 19.6% in those aged 70–79 years and was higher in men than in women (18.8% vs 10.8%).

Inclusion of mild deformities (20–24.9%) increased the prevalence to approximately 30%. Among radiologist-adjudicated fractures, 42.3% were mild, 53.5% moderate, and 4.2% severe.

Radiological assessment and observer agreement

Fracture classification was based on a combination of automated six-point morphometry, manual adjustment and radiologist verification. Interobserver agreement between radiologists was substantial (Fleiss' $\kappa = 0.74$), supporting consistency of morphometric fracture identification. Detailed interobserver agreement results are provided in Table S2. Agreement was consistent across thoracic and lumbar regions (Fig. S1).

Agreement between the automated system and radiologist adjudication was lower ($\kappa = 0.31$), reflecting known challenges in distinguishing true fractures from physiological vertebral shape variation and degenerative change on DXA-based VFA. Examples of false-positive classifications related to vertebral tilt and scoliosis are shown in Figs. 2 and 3.

Most automated false-positive classifications were attributable to degenerative features, including osteophyte formation, endplate irregularity, vertebral wedging (including Scheuermann-type deformity), and spinal tilt (including scoliosis). Other imaging studies have reported anatomical variants such as Schmorl's nodes. Representative examples of common non-fracture abnormalities leading to false-positive automated classifications are shown in Fig. S4. The distribution of false-positive classifications by vertebral level and category is shown in Fig. S3. These findings highlight the importance of expert radiological review, particularly for borderline or mild deformities (Fig. 4).

Fracture distribution and morphology

Fractures were most frequently located in the mid-thoracic and thoracolumbar regions. The anatomical distribution of fractures by vertebral level is shown in Fig. 6. Morphometric height loss demonstrated a continuous distribution, with radiologist-classified fractures showing greater degrees of compression compared with non-fractured vertebrae.

The proportion of individuals with multiple fractures increased with age, although multiple fractures were also observed in younger participants. The distribution of fracture counts by age group is shown in Fig. 5.

Clinical predictors

In multivariable analysis, age and sex were the strongest predictors. Participants aged 70–79 years had increased odds of fracture compared with those aged 40–49 years (adjusted OR 2.12, 95% CI 1.15–4.21; $p = 0.015$), while

Table 1 Fracture (genant moderate and severe) prevalence and power assessment by demographic and clinical characteristics

Variable	Category	Fractures (*n*/*N*, %)	MDD at 80% power (pp)	Power assessment
Age group	40–49	13/138 (9.4%)	Reference	
Age group	50–59	82/752 (10.9%)	7.6	Adequate
Age group	60–69	182/1153 (15.8%)	7.4	Adequate
Age group	70–79	79/403 (19.6%)	8.1	Adequate
Sex	Male	216/1151 (18.8%)	Reference	
Sex	Female	140/1295 (10.8%)	4.4	Strong
Ethnicity	British	326/2238 (14.6%)	Reference	
Ethnicity	African	0/6 (0.0%)	40.4	Underpowered
Ethnicity	Other	27/178 (15.2%)	7.7	Adequate
Ethnicity	South Asian	3/24 (12.5%)	20.3	Underpowered
BMI group	Normal	98/895 (10.9%)	Reference	
BMI group	Underweight	1/10 (10.0%)	27.8	Underpowered
BMI group	Overweight	163/1053 (15.5%)	4.0	Strong
BMI group	Obese	94/488 (19.3%)	4.9	Strong
BMD	Normal	250/1724 (14.5%)	Reference	
BMD	Osteopaenia	74/553 (13.4%)	4.8	Strong
BMD	Osteoporosis	20/102 (19.6%)	10.1	Limited
Simple analgesics	FALSE	236/1574 (15.0%)	Reference	
Simple analgesics	TRUE	120/872 (13.8%)	4.2	Strong
NSAID	FALSE	251/1686 (14.9%)	Reference	
NSAID	TRUE	105/760 (13.8%)	4.4	Strong
Opiate	FALSE	347/2405 (14.4%)	Reference	
Opiate	TRUE	9/41 (22.0%)	15.5	Underpowered
Calcium	FALSE	341/2394 (14.2%)	Reference	
Calcium	TRUE	15/52 (28.8%)	13.7	Limited
Anti-resorptive	FALSE	341/2383 (14.3%)	Reference	
Anti-resorptive	TRUE	15/63 (23.8%)	12.5	Limited
Vitamin D	FALSE	314/2157 (14.6%)	Reference	
Vitamin D	TRUE	42/289 (14.5%)	6.2	Adequate
Steroid	FALSE	352/2428 (14.5%)	Reference	
Steroid	TRUE	4/18 (22.2%)	23.3	Underpowered
Back pain for the last 3 months	TRUE	81/565 (14.3%)	Reference	
Back pain for the last 3 months	FALSE	275/1881 (14.6%)	4.7	Strong

Fracture prevalence and power assessment by demographic and clinical characteristics. Values are shown as the number of participants with a fracture divided by the total within each category, with percentages in parentheses. *MDD* minimum detectable difference in fracture prevalence at 80% power. Power assessment classifies each variable as Strong (< 5 percentage points), Adequate (5–10 pp), Limited (10–15 pp), or Underpowered (> 15 pp)

women had lower odds than men (adjusted OR 0.51, 95% CI 0.40–0.66; $p < 0.001$).

Bone mineral density showed only a weak association with fracture. Osteopaenia was not associated with increased risk, and osteoporosis showed a modest association (adjusted OR 1.95, 95% CI 1.11–3.28). Fractures were frequently present in individuals with normal BMD.

Table 2 Unadjusted and adjusted odds ratios for moderate or severe vertebral fracture (≥ 25% vertebral height reduction) at the participant level

Variable	Category	Unadjusted OR (95% CI)	*p* (level, unadj)	Adjusted OR (95% CI)	*p* (level, adj)	*p* (global)
Age_Group	40–49	1 (reference)		1 (reference)		0.000
	50–59	1.14 (0.64–2.18)	0.660	1.21 (0.67–2.39)	0.542	
	60–69	1.75 (1.01–3.27)	0.046	1.75 (0.99–3.39)	0.056	
	70–79	2.28 (1.27–4.37)	0.005	2.12 (1.15–4.21)	0.015	
Sex	Male	1 (reference)		1 (reference)		0.000
	Female	0.53 (0.42–0.66)	0.000	0.51 (0.40–0.66)	0.000	
Ethnicity	British	1 (reference)		1 (reference)		0.233
	African	0.45 (0.00–3.82)	0.542	0.36 (0.00–3.23)	0.434	
	Other	1.06 (0.68–1.60)	0.777	1.17 (0.74–1.78)	0.493	
	South Asian	0.95 (0.25–2.63)	0.934	1.00 (0.26–2.82)	0.996	
BMI_Group	Normal	1 (reference)		1 (reference)		0.000
	Underweight	1.28 (0.14–5.63)	0.788	0.95 (0.10–4.53)	0.951	
	Overweight	1.49 (1.14–1.95)	0.003	1.39 (1.05–1.84)	0.023	
	Obese	1.94 (1.43–2.64)	0.000	1.99 (1.43–2.77)	0.000	
BMD	Normal	1 (reference)		1 (reference)		0.000
	Osteopaenia	0.91 (0.69–1.20)	0.527	1.01 (0.75–1.35)	0.942	
	Osteoporosis	1.46 (0.86–2.37)	0.151	1.95 (1.11–3.28)	0.020	
Simple analgesics	FALSE	1 (reference)		1 (reference)		0.027
	TRUE	0.91 (0.71–1.15)	0.414	0.86 (0.66–1.11)	0.242	
NSAID	FALSE	1 (reference)		1 (reference)		0.031
	TRUE	0.92 (0.72–1.17)	0.496	0.95 (0.73–1.24)	0.733	
Opiate	FALSE	1 (reference)		1 (reference)		0.059
	TRUE	1.73 (0.79–3.46)	0.162	1.68 (0.75–3.47)	0.198	
Calcium	FALSE	1 (reference)		1 (reference)		0.002
	TRUE	2.49 (1.32–4.46)	0.006	2.67 (1.26–5.41)	0.011	
Anti resorptive	FALSE	1 (reference)		1 (reference)		0.012
	TRUE	1.91 (1.03–3.35)	0.039	1.39 (0.64–2.81)	0.390	
Vitamin D	FALSE	1 (reference)		1 (reference)		0.063
	TRUE	1.01 (0.70–1.41)	0.971	1.03 (0.70–1.48)	0.875	
Steroid	FALSE	1 (reference)		1 (reference)		0.167
	TRUE	1.83 (0.56–4.92)	0.293	1.70 (0.50–4.75)	0.362	
Back pain for the last 3 months	FALSE	1 (reference)		1 (reference)		0.045
	TRUE	0.98 (0.75–1.28)	0.887	0.94 (0.71–1.25)	0.695	

Unadjusted and adjusted odds ratios for moderate or severe vertebral fracture (≥ 25% vertebral height reduction; Genant grade ≥ 2) at the participant level. Odds ratios were estimated using Firth penalised logistic regression to reduce small-sample bias. Adjusted models included age group, sex, ethnicity, body mass index category, bone mineral density category, medication exposures, and recent back pain. Reference categories are shown as 1 (reference). Global *p*-values represent likelihood-ratio tests for the overall association of each variable with fracture risk

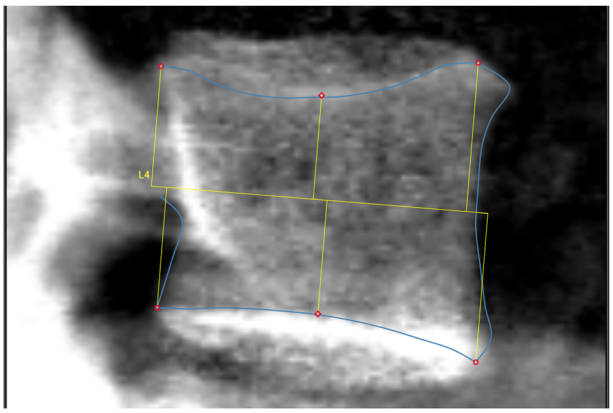


Fig. 2 False-positive fracture due to vertebral tilt. Lateral DXA image demonstrating scoliosis-related vertebral tilt. Incorrect endplate selection by automated morphometry results in apparent vertebral compression in the absence of a true fracture. Images reproduced by kind permission of UK Biobank ©

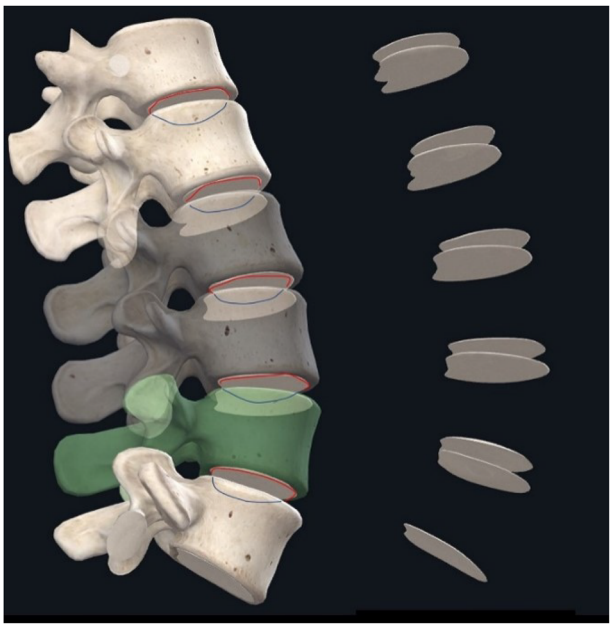


Fig. 3 False-positive fracture due to endplate misregistration. Example demonstrating how vertebral tilt or scoliosis may lead to incorrect selection of opposing endplate margins by automated morphometry, resulting in an apparent fracture. Images reproduced by kind permission of UK Biobank ©

Body mass index demonstrated a stronger relationship, with obesity independently associated with fracture (adjusted OR 1.99, 95% CI 1.43–2.77). Recent back pain was not associated with fracture presence.

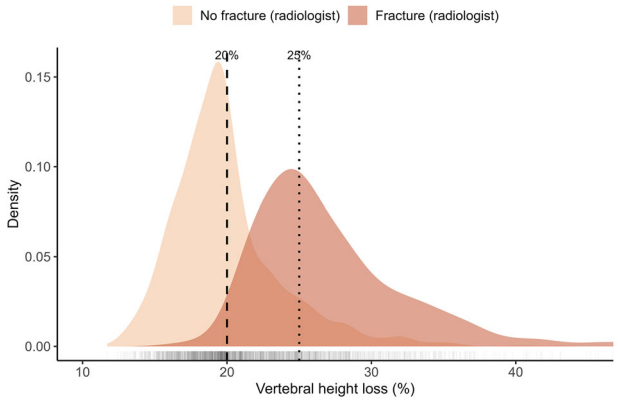


Fig. 4 Relationship between vertebral height loss and fracture classification. Density distributions of percentage vertebral height loss derived from automated morphometry, stratified by radiologist-adjudicated fracture status. Fractured vertebrae demonstrate greater degrees of compression. Vertical lines indicate commonly used morphometric thresholds (20% and 25%)

Prediction modelling

Prediction models incorporating clinical variables showed limited discrimination (sensitivity 44.4%, specificity 68.2%), indicating that imaging-based assessment identifies fractures not captured by conventional risk factors.

Discussion

Key findings

In this population-based cohort of asymptomatic adults, moderate or severe vertebral fractures were identified in 14.6% of individuals, with prevalence increasing with age and consistently higher in men than in women. Fractures were already present in younger participants and were frequently observed in individuals without low BMD. Conventional clinical risk factors showed limited ability to identify affected individuals.

Comparison with existing literature

The prevalence observed in this study is at the upper end of previously reported ranges, including those from the European Vertebral Osteoporosis Study and other imaging-based cohorts. This likely reflects the use of a standardised morphometric approach applied across the entire thoracolumbar spine, combined with radiologist verification. Inclusion of asymptomatic participants and broader vertebral coverage may also contribute to higher detection rates compared with studies restricted to symptomatic or older populations.

Radiological considerations

A key strength of this study is the use of a structured radiological workflow combining automated six-point

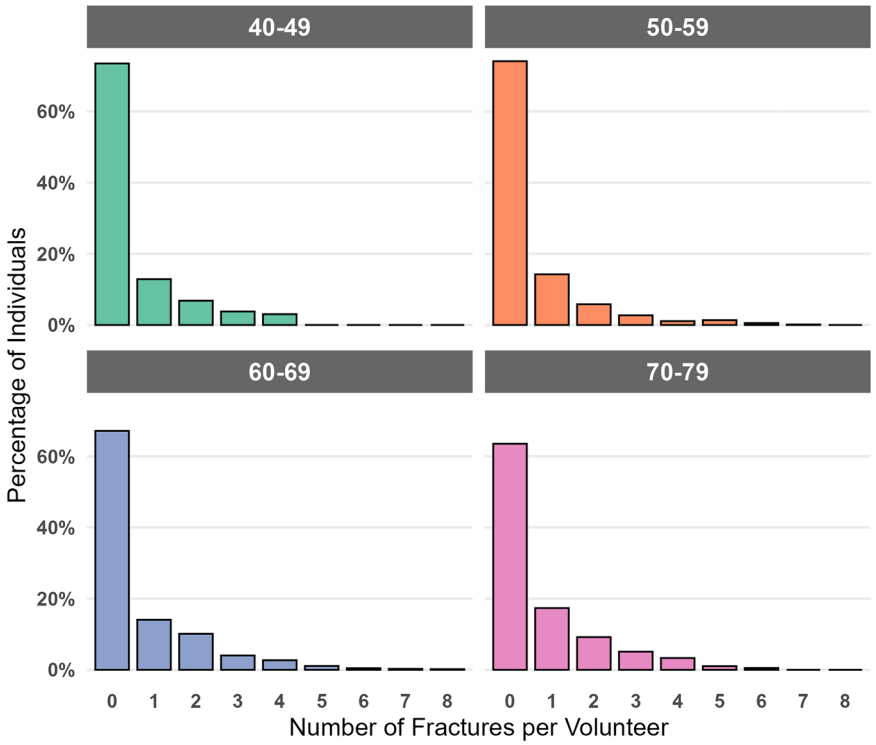


Fig. 5 Distribution of vertebral fracture counts by age group. Number and proportion of individuals with 0–8 vertebral fractures (≥ 25% height loss) across age groups (40–79 years), demonstrating increasing fracture burden with age

morphometry with manual correction and expert review. Interobserver agreement between radiologists was substantial, supporting the reproducibility of morphometric fracture assessment on DXA images.

Agreement between automated outputs and radiologist adjudication was lower, largely due to challenges in distinguishing true fractures from degenerative change and physiological vertebral shape variation. False-positive classifications were most commonly related to osteophyte formation, endplate irregularity, and anatomical variants. These findings emphasise that, although automated approaches can assist detection, radiologist interpretation remains essential for accurate classification, particularly in borderline cases and mild deformities.

The anatomical distribution of fractures, with clustering in the mid-thoracic and thoracolumbar regions, as demonstrated in Fig. 6, is consistent with known biomechanical stress patterns and supports the biological plausibility of the findings.

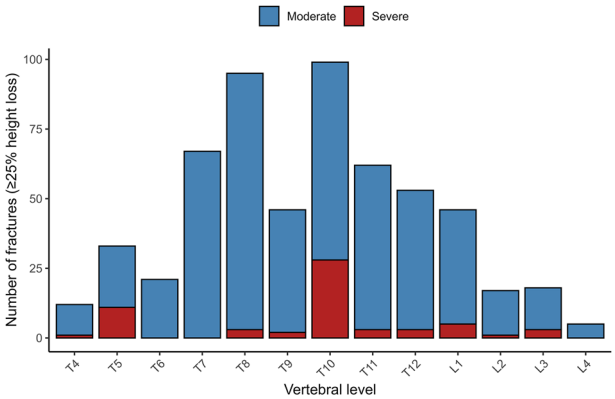


Fig. 6 Vertebral fracture distribution by spinal level. Number of radiologist-adjudicated vertebral fractures from T4 to L4. Fractures were classified as moderate (≥ 25% height loss) or severe (≥ 40%). Distribution demonstrates clustering in the mid-thoracic and thoracolumbar regions

Interpretation of risk factors

Age and sex were the strongest predictors of vertebral fracture. The higher prevalence observed in men contrasts with the traditional pattern described for clinically apparent osteoporotic fractures and suggests that asymptomatic morphometric deformities may have a different epidemiological profile. This may reflect differences in cumulative mechanical loading, vertebral geometry, and patterns of degenerative change. In addition, DXA-derived BMD is a two-dimensional measure and does not fully capture bone quality or structural integrity.

The weak association between BMD and fracture presence in this study is therefore consistent with the multifactorial nature of vertebral fracture risk and the limitations of BMD as a surrogate for vertebral strength.

Bone mineral density showed only a weak association with fracture presence, and a substantial proportion of fractures occurred in individuals with normal BMD. This highlights the limitations of BMD as a surrogate for vertebral strength and suggests that additional factors, including vertebral geometry, trabecular structure, and cumulative mechanical loading, contribute to fracture risk.

In contrast, body mass index demonstrated a clearer association, with obesity independently associated with fracture. This may reflect increased axial loading or altered spinal biomechanics rather than classical osteoporotic mechanisms.

Recent back pain was not associated with fracture presence, reinforcing the concept that many vertebral fractures remain clinically silent and are not reliably identified on the basis of symptoms alone.

Clinical implications

These findings have implications for radiological practice and fracture detection strategies. Opportunistic VFA on DXA imaging can identify a substantial burden of previously unrecognised disease. The limited predictive value of clinical risk factors suggests that reliance on risk-based screening alone may fail to detect many individuals with vertebral fractures.

From a radiological perspective, structured assessment of vertebral morphology and careful differentiation between fracture and non-fracture deformity are essential, particularly when automated tools are used.

Limitations

This study has several limitations. The UK Biobank cohort comprises volunteers and may not be fully representative of the general population. The cross-sectional design does not allow determination of fracture timing or progression. Information on symptom severity and duration was limited, restricting interpretation of symptom–fracture relationships. Although the combined automated and radiologist-reviewed approach is likely to improve specificity, some misclassification of vertebral deformity is unavoidable in the absence of an external reference standard. Finally, DXA-based VFA has lower spatial resolution than radiography or CT, although it performs well for moderate and severe fractures, which were the primary outcome in this study.

Conclusion

Silent vertebral fractures are common in asymptomatic adults, are present from midlife, and are more prevalent in men. Many occur in individuals without low BMD and are not predicted by conventional clinical risk factors. Radiological assessment, including opportunistic evaluation on DXA imaging, plays a key role in identifying this under-recognised condition.

Abbreviations

AI	Artificial intelligence
BMD	Bone mineral density
BMI	Body mass index
CI	Confidence interval
CT	Computed tomography
DXA	Dual-energy X-ray absorptiometry
NSAID	Non-steroidal anti-inflammatory drug
OR	Odds ratio
VFA	Vertebral fracture assessment

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1007/s00330-026-12947-0.

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The late Dr Paul Bromiley (University of Manchester) for his assistance with the artificial intelligence algorithm. This paper forms part of a thesis written by David Wilson (D.W.) for the Doctor of Medicine by Research degree at Imperial College London. *Use of Artificial Intelligence Tools*: during the preparation of this manuscript: the authors used ChatGPT (OpenAI) to assist with language editing, clarity, and organisation of the text, and to support the drafting and checking of statistical code in R under author supervision. Grammarly was used for spelling and grammar correction. These tools were not used for study design, data acquisition, data analysis, or interpretation of results. All content generated or revised using these tools was reviewed and approved by the authors, who take full responsibility for the accuracy and integrity of the work.

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Data availability

The data underlying this study are available from the UK Biobank (http://www.ukbiobank.ac.uk/). Access to this data requires an application and approval from the UK Biobank Access Management System.

Compliance with ethical standards

Guarantor

The scientific guarantor of this publication is David Wilson, Member of Congregation, University of Oxford, Medical Sciences Division.

Conflict of interest

The authors of this manuscript declare relationships with the following companies: David Wilson and Georgina Allen are Directors of St Luke's Radiology Oxford Ltd, a private and NHS outsourced radiology practice registered with the Care Quality Commission. Iain Wilson is affiliated with Oxehealth. David Wilson, Richard Whitehouse, Georgina Allen, Fiona Saunders, and Richard Abel declare no other competing interests.

Statistics and biometry

Statistical advice was provided by Dr John Pinney (Imperial College London) and Dr Paul Bassett.

Informed consent

Written informed consent was not required for this study because the data were obtained from the UK Biobank, and all participants had consented to the anonymised use of their data. The appropriate ethics committee waived consent requirements.

Ethical approval
UK Biobank has full ethical approval from the National Information Governance Board for Health and Social Care and the North-West Multi-Centre Research Ethics Committee (11/NW/0382). Permission to access and analyse UK Biobank data for this study was approved under UKB application number 17295. The Imperial College London Bone Laboratory holds regular Patient in Research meetings to discuss the project's nature and findings with the patient panel. This project was discussed at a meeting in 2019.

Study subjects or cohorts overlap
Some participants included in this analysis have been reported previously in other UK Biobank imaging studies, including the AUGMENT study.

Methodology

- Retrospective observational study
- Cross-sectional analysis
- Multicentre imaging cohort

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