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Opportunistic screening for the presence of vertebral fractures using L1 trabecular bone density on non-contrast chest CT

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ABSTRACT

Aims: To evaluate the effectiveness of opportunistic screening using L1 trabecular density on non-contrast chest CT for identifying the presence of vertebral fractures.

Methods: This retrospective cross-sectional study included 385 adult patients (≥40 years) who underwent non-contrast chest CT. L1 trabecular attenuation was measured at the mid-vertebral level. Vertebral compression fractures were assessed. The diagnostic performance of L1 hounsfield unit (HU) and clinical variables was evaluated using regression and ROC analyses.

Results: Vertebral fractures were found in 137 patients (35.6%). Mean L1 density was significantly lower in the fracture group (71.2±35.1 HU) compared to the non-fracture group (134.4±36.6 HU, p<0.001). L1 HU showed a strong inverse correlation with age (r=-0.952). ROC analysis for L1 HU yielded an AUC of 0.882. An optimal threshold of 94 HU demonstrated 86.9% sensitivity and 89.1% specificity.

Conclusion: L1 trabecular attenuation on routine non-contrast chest CT serves as a useful opportunistic screening tool associated with the presence of vertebral fractures.

Keywords: Osteoporosis, osteoporotic fractures, computed tomography, mass screening, bone density

INTRODUCTION

With the aging global population, osteoporosis and associated fragility fractures have become a universal public health problem, resulting in significant morbidity, mortality, and a substantial burden on healthcare economics.[1] To frame this clinical challenge, it is important to clearly distinguish between the underlying pathology and its clinical manifestations: osteoporosis is a systemic skeletal disorder characterized by microarchitectural deterioration; bone mineral density (BMD) is the primary quantitative metric used to diagnose this underlying condition; and vertebral compression fractures (VCF) represent the most common, critical clinical consequence of this compromised bone strength. Although these fractures dramatically reduce patients' quality of life and are associated with an increased risk of death, they are often underdiagnosed in clinical practice due to their asymptomatic or subtle presentation, thereby missing opportunities for treatment.[2] In current clinical guidelines, the gold standard method for assessing fracture risk and diagnosing osteoporosis is the calculation of BMD using dual-energy X-ray absorptiometry (DXA). However, limited community-based access to DXA scans, low compliance with screening protocols, and conditions such as aortic vascular calcifications, osteophytes, or degenerative joint diseases which can artificially elevate BMD values, limit the diagnostic accuracy of this method in certain situations.[3]

The concept of "opportunistic screening," which has gained increasing acceptance in the field of radiology in recent years, essentially involves using existing computed tomography (CT) images obtained for a different clinical indication (e.g., lung cancer screening,[4] suspected pneumonia, cardiovascular evaluation, COPD,[5] pulmonary embolism[6]) to obtain quantitative data on bone quality without subjecting the patient to additional radiation exposure, cost, or time loss. Given the anatomical location of the L1 vertebra, which is included in the imaging field in the vast majority of thoracic and abdominal CT examinations, Hounsfield unit (HU)-based trabecular attenuation measurements derived from

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this vertebral body have become an extremely ideal, practical, and reproducible biomarker for osteoporosis screening.[4,7] The literature emphasizes that low trabecular density of the L1 vertebra not only reflects current bone loss but also serves as an independent factor in predicting the risk of future osteoporotic fractures.[8,9]

The aim of this study is to investigate the effectiveness of opportunistic screening using measurements of trabecular density at the L1 vertebra in non-contrast chest CT scans routinely obtained for predicting the risk of osteoporosis and vertebral fractures, and to quantitatively assess the relationship between these measurements and clinical predictors such as age, gender, body-mass index (BMI), and chronic corticosteroid use.

METHODS

This study was conducted with the approval of the Necmettin Erbakan University Ethics Committee for Non-pharmaceutical and Non-medical Device Researches (Date: 27.02.2026, Decision No: 2026/6369). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. This study was designed as a retrospective, cross-sectional study to assess the risk of osteoporosis and vertebral fractures. Due to the retrospective nature of the study, the requirement for written informed consent was waived.

Adult patients (≥ 40 years of age) who underwent non-contrast chest CT scans for various clinical indications (predominantly suspected pulmonary infections, chronic obstructive pulmonary disease evaluation, and lung cancer screening) at the Radiology Clinic of Necmettin Erbakan University Hospital between January 1, 2024, and January 1, 2025, were retrospectively evaluated. During the initial radiological database screening, consecutive scans were reviewed, and patients were systematically excluded if they had severe vertebral deformity, metastatic lesions in the L1 vertebral body, hemangioma, a history of vertebroplasty, or severe metallic artifacts. Following this rigorous exclusion process, a final cohort of 385 eligible patients was established and included in the analysis. To ensure standardization and homogeneity in the imaging protocol, this study included non-contrast-enhanced chest CT scans acquired at a standard dose using a 256-slice dual-energy Siemens Somatom Drive CT scanner.

Measurements of trabecular density in the L1 vertebra were performed in accordance with the standard quantitative measurement methodology previously validated in the literature. The L1 vertebral body was clearly localized on reconstructed axial, coronal, and sagittal images of the patients. A standard elliptical region of interest (ROI) was placed at the mid-vertebral level within the anterior 1/3 trabecular area of the L1 vertebral body on axial images, carefully avoiding the cortical bone margins, the posterior venous plexus, and focal sclerotic bone islands (**Figure 1**). The mean attenuation values obtained from this region were recorded in HU.

To ensure measurement reliability, L1 trabecular attenuation values were measured independently by two radiologists.

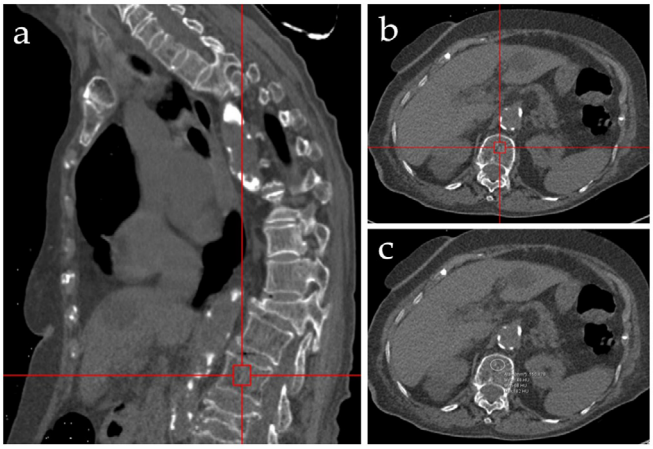


Figure 1. Measurement of L1 trabecular attenuation on non-contrast chest CT

The L1 vertebra is localized using sagittal (a) and axial (b) planes. An elliptical ROI is placed within the anterior trabecular bone (c) to obtain the mean HU value. CT: Computed tomography, ROI: Region of interest, HU: Hounsfield unit

The inter-observer agreement was excellent [intraclass correlation coefficient (ICC)=0.88]. The mean value of the two independent measurements was calculated and used for all subsequent statistical analyses.

The presence of VCF was assessed using sagittal CT reconstructions. In accordance with the Genant visual semi-quantitative (SQ) staging system, patients demonstrating a loss of at least 20% in normal vertebral height (Stage 1, mild fracture, or greater) were considered fracture-positive. Clinical data for the patients (age, gender, BMI, and history of systemic chronic corticosteroid use) were obtained from the hospital information management system.[10]

Statistical Analysis

The data were performed using SPSS v24.0 (IBM Corp., Armonk, NY, USA) and Jamovi v2.6 (Sydney, Australia). Statistical analyses were conducted by selecting tests appropriate for the distribution characteristics of the data. The normality of continuous variables was tested using the Shapiro-Wilk test. For variables showing a normal distribution, the independent samples t-test was applied; for those not showing a normal distribution, the Mann-Whitney U test was used. Categorical variables were expressed as frequencies and percentages and analyzed using the Chi-square test. Spearman's rank correlation analysis (rho) was used to determine the correlation between continuous variables. Univariate and multivariate logistic regression models were constructed to identify independent clinical factors predicting fracture risk. In the multivariate models, potential multicollinearity among variables was examined using the variance inflation factor (VIF) analysis. Receiver operating characteristic (ROC) analysis was performed to determine the diagnostic accuracy of the L1 HU measurement in distinguishing vertebral fractures and to identify the optimal cutoff value, and the Youden index was calculated. A p-value of <0.05 was considered statistically significant.

RESULTS

Study Population Characteristics

A total of 385 patients were included in the final analysis, comprising 231 female (60.0%) and 154 male (40.0%), with a mean age of 68.8±12.7 years (range: 44-90 years). The mean

BMI was 26.8±3.7 kg/m². Chronic corticosteroid use was documented in 36 patients (9.4%). The overall prevalence of vertebral fracture was 35.6% (n=137). The mean L1 vertebral trabecular attenuation measured on thoracic CT was 111.9±47.0 HU, with a median of 114 HU (interquartile range [IQR]: 70-154 HU). No missing data were present for any variable. A complete summary of baseline characteristics, stratified by fracture status, is presented in **Table 1**.

Table 1. Baseline demographic and clinical characteristics of the study population, stratified by vertebral fracture status

Variable	Overall (n=385)	VF-present (n=137)	VF-absent (n=248)	p-value
Age (years)	68.8±12.7	79.9±8.2	62.7±10.5	<0.001
Female gender, n (%)	231 (60.0)	130 (94.9)	101 (40.7)	<0.001
BMI (kg/m²)	26.8±3.7	26.1±3.6	27.2±3.6	0.006
Chronic steroid use, n (%)	36 (9.4)	28 (20.4)	8 (3.2)	<0.001
L1 vertebral density, HU-mean±SD	111.9±47.0	71.2±35.1	134.4±36.6	<0.001
L1 vertebral density, HU-median (IQR)	114 (70-154)	62 (48-82)	138 (110-162)	<0.001

Continuous variables are expressed as mean±SD or median (IQR); categorical variables as n (%). Independent-samples t-test or Mann-Whitney U-test for continuous variables; Chi-square test for categorical variables. SD: Standard deviation, IQR: Interquartile range, VF: Vertebral fracture, BMI: Body-mass index, HU: Hounsfield units

Comparison of Clinical Variables Between Patients with and Without Vertebral Fracture

Patients who sustained a vertebral fracture were significantly older than those without fracture (79.9±8.2 vs. 62.7±10.5 years; t=16.640, p<0.001). BMI was modestly lower in the fracture group (26.1±3.6 vs. 27.2±3.6 kg/m²; p=0.006), although the magnitude of this difference was clinically limited.

A strikingly disproportionate gender distribution was observed across fracture groups. Vertebral fractures were present in 130 of 231 female (56.3%) but in only 7 of 154 male (4.5%), a difference that was highly statistically significant (χ^2=105.633, p<0.001). Chronic steroid use was more prevalent in fracture patients (20.4% vs. 3.2%; χ^2=28.847, p<0.001), conferring an unadjusted odds ratio (OR) of 7.71 (95% CI: 3.40-17.46).

L1 vertebral HU values were substantially lower in the fracture group [mean: 71.2±35.1 HU; median: 62 HU (IQR: 48-82)] than in the fracture-absent group [mean: 134.4±36.6 HU; median: 138 HU (IQR: 110-162)]. Given that Shapiro-Wilk testing confirmed non-normal distributions in both subgroups (p<0.001 for both), the Mann-Whitney U-test was applied and confirmed a highly significant difference (U=4013.5, p<0.001).

Association of L1 Vertebral HU with Clinical Variables

Spearman rank-order correlation revealed a strong inverse relationship between L1 vertebral HU and age (ρ=-0.952, p<0.001), indicating a progressive decline in trabecular bone density with advancing age in this cohort. A weak positive correlation was observed between L1 HU and BMI (r=0.164, p=0.001), while BMI itself did not emerge as a clinically dominant determinant of density in multivariable analyses.

Female patients exhibited significantly lower L1 HU values compared to males (94.5±48.9 HU vs. 138.0±28.5 HU; t=-9.949, p<0.001). Similarly, patients receiving chronic corticosteroid therapy had markedly lower trabecular attenuation than those without steroid exposure [median: 48 HU (IQR: 38-54) vs. 120 HU (IQR: 80-156); t=-9.008, p<0.001].

Vertebral Fracture Prevalence Across L1 HU-Based Density Categories

Patients were stratified into three clinically informative HU-based density categories. Among the 121 patients (31.4%) with severely reduced trabecular density (<80 HU), vertebral fractures were identified in 100 cases (82.6%). In the intermediate category (80-120 HU; n=90, 23.4%), fractures occurred in 24 patients (26.7%). In contrast, of the 174 patients (45.2%) with HU values exceeding 120, only 13 (7.5%) had sustained vertebral fractures. The gradient in fracture risk across these three strata was highly pronounced, underscoring the clinical utility of L1 HU as a categorical risk stratification tool. Fracture prevalence by HU category is detailed in **Table 2**.

Table 2. Vertebral fracture prevalence stratified by L1 trabecular density category

L1 HU category	n	VF-present, n (%)	VF-absent, n (%)
<80 HU (severely reduced)	121	100 (82.6)	21 (17.4)
80-120 HU (moderately reduced)	90	24 (26.7)	66 (73.3)
>120 HU (normal/mildly reduced)	174	13 (7.5)	161 (92.5)

HU: Hounsfield units, VF: Vertebral fracture

Logistic Regression Analyses for Vertebral Fracture Risk

In univariable logistic regression analyses, older age (OR=1.196; 95% CI: 1.154-1.239; p<0.001), female gender (OR=27.03; 95% CI: 12.13-60.25; p<0.001), chronic steroid use (OR=7.71; 95% CI: 3.40-17.46; p<0.001), and lower L1 HU (OR per HU=0.958; 95% CI: 0.951-0.966; p<0.001) were all significantly associated with vertebral fracture. Higher BMI was inversely associated with fracture risk in univariable analysis (OR=0.922; 95% CI: 0.869-0.977; p=0.006).

A multivariable logistic regression model incorporating all five predictors simultaneously yielded a Nagelkerke R^2 of 0.632 and an AUC of 0.911, indicating excellent overall discriminative capacity. However, VIF analysis revealed substantial multicollinearity between age and L1 vertebral HU (VIFage=29.3; VIFL1HU=11.2; VIFBMI=51.6), attributable to the near-perfect inverse correlation between these variables (Spearman ρ=-0.952). As a consequence, in the presence of age, the independent contributions of L1 HU (adjusted OR=0.994; 95% CI: 0.979-1.010; p=0.454), chronic steroid use (adjusted OR=0.865; 95% CI: 0.296-2.526; p=0.790), and BMI (adjusted OR=0.950; p=0.240) did not achieve statistical significance, while age (adjusted OR=1.119; 95% CI: 1.051-1.190; p<0.001) and female gender (adjusted OR=9.28; 95% CI: 3.87-22.25; p<0.001) remained independently significant. Full regression results are provided in **Table 3**.

Diagnostic Performance of L1 Vertebral HU for Vertebral Fracture Prediction

ROC analysis demonstrated that L1 vertebral HU measurement alone provided strong discriminative

Table 3. Univariable and multivariable logistic regression analysis of factors associated with vertebral fracture

Variable	Univariable OR (95% CI)		Adjusted OR (95% CI)*	p-value (adj.)
	OR (95% CI)	p-value		
Age (per year)	1.196 (1.154-1.239)	<0.001	1.119 (1.051-1.190)	<0.001
Female gender	27.03 (12.13-60.25)	<0.001	9.28 (3.87-22.25)	<0.001
BMI (per kg/m²)	0.922 (0.869-0.977)	0.006	0.950 (0.873-1.035)	0.240
Chronic steroid use	7.706 (3.402-17.46)	<0.001	0.865 (0.296-2.526)†	0.790
L1 vertebral density (per HU)	0.958 (0.951-0.966)	<0.001	0.994 (0.979-1.010)†	0.454

Reference categories: male gender; no steroid use. *Adjusted for all listed covariates simultaneously. †Significance attenuated by high multicollinearity with age (VIF>10). OR: Odds ratio, CI: Confidence interval, BMI: Body-mass index, HU: Hounsfield units, VIF: Variance inflation factor, NS: Not significant

performance for vertebral fracture prediction, with an area under the curve (AUC) of 0.882 (95% CI: 0.843-0.921) (**Figure 2**). The Youden index identified an optimal HU threshold of 94 HU, at which the sensitivity was 86.9%, specificity was 89.1%, positive predictive value (PPV) was 81.5%, negative predictive value (NPV) was 92.5%, and overall diagnostic accuracy was 88.3%. The full multivariable model achieved an AUC of 0.911, representing a modest absolute increment over the single-parameter L1 HU measure. Diagnostic performance metrics at the optimal threshold are summarized in **Table 4**.

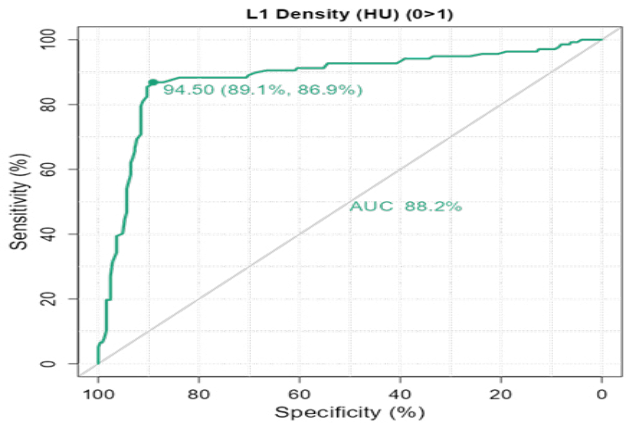


Figure 2. ROC curve evaluating the performance of L1 trabecular density in predicting vertebral fracture

The optimal threshold of 94 HU demonstrates a sensitivity of 86.9% and a specificity of 89.1% (AUC=0.882). HU: Hounsfield unit, AUC: Area under the receiver operating characteristic curve, ROC: Receiver operating characteristic

Table 4. Diagnostic performance characteristics of L1 vertebral HU measurement for the prediction of vertebral fracture at the Youden-optimal threshold of 94 HU

Parameter	Value	95% CI
AUC (L1 HU alone)	0.882	0.843-0.921
AUC (full multivariable model)	0.911	—
Optimal cut-off (Youden index)	94 HU	—
Sensitivity	86.9%	—
Specificity	89.1%	—
Positive predictive value (PPV)	81.5%	—
Negative predictive value (NPV)	92.5%	—
Overall accuracy	88.3%	—

The full multivariable model AUC (0.911) is provided for comparison. HU: Hounsfield unit, CI: Confidence interval, AUC: Area under the receiver operating characteristic curve, PPV: Positive predictive value, NPV: Negative predictive value

DISCUSSION

Our study suggests that the HU density of the L1 vertebra is a reliable and useful biomarker for predicting the presence of fractures in an aging population among individuals who have undergone non-contrast chest CT scans for various indications.

Although the HU thresholds defined in the literature for opportunistic CT scans vary, our findings are largely consistent with leading reference studies. In a large-scale cohort study, Pickhardt and colleagues[7] determined that the optimal L1 attenuation value for detecting osteoporosis is 100 HU; sensitivity and specificity were found to be high at this threshold. Additionally, in another study investigating vertebral fractures,[11] the threshold value was determined to be 95 HU. The 94 HU value identified in our cohort nearly matches literature, suggesting the potential consistency of this metric, although prospective external validation is necessary to truly confirm its reproducibility across different populations.

In a normative data study by Jang et al.[12] involving more than 20.000 adults, it was found that L1 trabecular attenuation exhibited a linear decrease of 2.5 HU per year of age. In our cohort as well, age stratification analysis showed that the mean, which was 165 HU in patients under 60 years of age, dropped sharply to 50 HU in those over 80 years of age. A critical statistical finding in our study was the substantial multicollinearity observed between age and L1 attenuation (r=-0.952, VIF>10). Because trabecular bone density physiologically declines with advancing age, these two variables share highly overlapping variance in predicting fracture risk. Consequently, when both were included in the multivariable regression model, L1 HU lost its independent statistical significance. However, from a clinical perspective, this does not diminish the value of L1 HU. Rather than viewing L1 HU as a strictly independent risk factor, it should be interpreted as a quantifiable imaging biomarker that physically manifests and measures the extent of age-related bone deterioration. In opportunistic screening, L1 HU provides an objective, patient-specific metric of bone quality that chronological age alone cannot visually demonstrate.

The fact that female patients have a dramatically higher fracture rate compared to male and that their average HU values are significantly lower reflects the accelerated destructive effects of postmenopausal estrogen deficiency on bone microarchitecture.[13] The identification of female gender as an independent factor increasing fracture risk in our study further supports the necessity of prioritizing postmenopausal women as the primary target population in osteoporosis screening.

In our study, the decline in L1 trabecular density to low levels and the associated increased risk of fracture in patients receiving chronic steroid therapy may serve as a critical strategy for this patient group to incorporate opportunistic chest CT scans into routine follow-up, enabling the early detection of subclinical fractures and prompting further formal clinical evaluation (e.g., DXA referral) for the consideration of prophylactic anti-osteoporotic treatments.

Limitations

This study has several limitations that should be taken into account. First, since the study has a retrospective, cross-sectional, and single-center design, it is not possible to definitively establish a temporal causal relationship between decreasing HU values and the development of fractures. Additionally, the retrospective recruitment based on specific clinical indications introduces potential selection bias. Furthermore, the profound multicollinearity between age and L1 attenuation limits our ability to evaluate the truly independent contribution of trabecular density in multivariable prediction models. Second, the lack of concurrent DXA (T-score) data for the patients prevented a direct correlation between HU values and standard BMD scores. Third, a marked gender imbalance was present in our cohort, with a disproportionately high number of female in the fracture group; thus, the findings should be interpreted with caution when applied to male populations. Fourth, all scans included in the study were performed using the same specific CT scanner. The literature indicates that HU values detected in opportunistic scans may exhibit certain degrees of variation depending on the manufacturer, device generation, and scanning protocols. Finally, the optimal ROC cutoff value of 94 HU was derived and evaluated within the same cohort. This approach can lead to optimistic diagnostic performance estimates, underscoring the critical need for external validation. Therefore, caution is warranted when directly generalizing the findings of our study to other device ecosystems or unvalidated populations.

Our recommendations for future studies are to calibrate and validate the identified diagnostic thresholds using large-scale, prospective cohorts that include multiple institutions and different brands/models of CT systems. Additionally, performing L1 vertebral ROI delineation using AI-based automatic segmentation and deep learning algorithms without the need for human intervention will be an essential step toward seamlessly integrating opportunistic screening into the clinical workflow without increasing the workload of radiologists.

CONCLUSION

As a result, the measurement of trabecular density at the L1 vertebra derived from non-contrast chest CT scans is a useful, time-efficient, and non-invasive opportunistic screening tool for predicting the presence of osteoporosis and the risk of vertebral compression fractures.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was conducted with the approval of the Necmettin Erbakan University Ethics Committee for Non-Pharmaceutical and Non-medical Device Researches (Date: 27.02.2026, Decision No: 2026/6369).

Informed Consent

As this was a retrospective study, formal written informed consent was not required and was therefore not obtained. This retrospective study used pre-existing anonymized patient data. No additional intervention was performed, and there was no direct patient contact. The study was approved by the Ethics Committee, and the requirement for written informed consent was waived by the ethics committee.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Conceptualization: HE; Methodology: HE, HEK; Data Collection: HE, HEK; Formal Analysis: HE, AEA; Writing the Manuscript: HE; Writing-Review and Editing: AEA; Supervision: AEA, HEK.

REFERENCES

1. Vadera S, Osborne T, Shah V, Stephenson JA. Opportunistic screening for osteoporosis by abdominal CT in a British population. *Insights Imaging*. 2023;14(1):57. doi:10.1186/s13244-023-01400-1
2. Angeli A, Guglielmi G, Dovio A, et al. High prevalence of asymptomatic vertebral fractures in post-menopausal women receiving chronic glucocorticoid therapy: a cross-sectional outpatient study. *Bone*. 2006; 39(2):253-259. doi:10.1016/j.bone.2006.02.005
3. Zou D, Li W, Deng C, Du G, Xu N. The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. *Eur Spine J*. 2019;28(8):1758-1766. doi:10.1007/s00586-018-5776-9
4. Patel N, Dahl K, O'Rourke R, et al. Vertebral CT attenuation outperforms standard clinical fracture risk prediction tools in detecting osteoporotic disease in lung cancer screening participants. *Br J Radiol*. 2023;96(1151):20220992. doi:10.1259/bjr.20220992
5. Koç A, Ataş AE. Relationship between pulmonary artery-to-aorta ratio and hospital length of stay in chronic obstructive pulmonary disease exacerbations: a retrospective cohort analysis and clinical implications. *J Health Sci Med*. 2026;9(1):45-51. doi:10.32322/jhsm.1794663
6. Koc A, Vatansev H. Prognostic relevance of biochemical markers integrated with simplified pulmonary embolism severity index in acute pulmonary embolism. *Ann Clin Anal Med*. 2025;16(12):893-898. doi:10.4328/acam.22700
7. Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ, Binkley N. Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. *Ann Intern Med*. 2013;158(8):588-595. doi:10.7326/0003-4819-158-8-201304160-00003
8. Guenoun D, Champsaur P. Opportunistic computed tomography screening for osteoporosis and fracture. *Semin Musculoskelet Radiol*. 2023;27(4):451-456. doi:10.1055/s-0043-1771037
9. Lee SJ, Graffy PM, Zea RD, Ziemlewicz TJ, Pickhardt PJ. Future osteoporotic fracture risk related to lumbar vertebral trabecular attenuation measured at routine body CT. *J Bone Miner Res*. 2018;33(5): 860-867. doi:10.1002/jbmr.3383
10. Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. *J Bone Miner Res*. 1993; 8(9):1137-1148. doi:10.1002/jbmr.5650080915
11. Zhang SB, Xu HW, Yi YY, Hu T, Wang SJ, Wu DS. Evaluation of the use of CT attenuation for the prediction of subsequent vertebral fracture in patients with osteoporosis. *Pain Physician*. 2021;24(4):E493-E500.
12. Jang S, Graffy PM, Ziemlewicz TJ, Lee SJ, Summers RM, Pickhardt PJ. Opportunistic osteoporosis screening at routine abdominal and thoracic CT: normative L1 trabecular attenuation values in more than 20 000 adults. *Radiology*. 2019;291(2):360-367. doi:10.1148/radiol.2019181648
13. Khosla S, Monroe DG. Regulation of bone metabolism by sex steroids. *Cold Spring Harb Perspect Med*. 2018;8(1):a031211. doi:10.1101/cshperspect.a031211