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Region-specific QCT thresholds for osteoporosis assessment in the thoracic spine: why lumbar cut-offs fail

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Research Article

Keywords:

Posted Date: June 29th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9997520/v1

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at BMC Musculoskeletal Disorders on September 8th, 2026. See the published version at https://doi.org/10.1186/s12891-026-10430-x.

Abstract

Background

Quantitative computed tomography (QCT) is increasingly used for preoperative bone quality assessment in spine surgery. However, established QCT osteoporosis thresholds are based on lumbar reference regions and are frequently extrapolated to the thoracic spine, despite anatomical and biomechanical differences.

Purpose

To evaluate whether lumbar QCT thresholds are transferable to the thoracic spine and to derive thoracic mean and subregional QCT cut-offs equivalent to established lumbar ACR thresholds.

Methods

In this retrospective study, trabecular volumetric bone mineral density (vBMD, mg/cm³) was assessed using QCT in 227 patients (mean age 66 ± 16 years). Thoracic vBMD was calculated as the mean of Th1–Th10, and lumbar vBMD as the mean of Th11–L4. Segmental vBMD distribution was analyzed, and the thoracic–lumbar relationship was modeled using Deming regression. Thoracic cut-offs equivalent to ACR lumbar thresholds (80/120 mg/cm³) were derived for the thoracic mean and for upper (Th1–Th4), mid (Th5–Th8), and lower thoracic regions (Th9–Th10).

Results

Thoracic vBMD was significantly higher than lumbar vBMD (102.5 ± 44.1 vs. 85.1 ± 44.6 mg/cm³). In patients with evaluable measurements in both regions (N = 101), thoracic vBMD exceeded lumbar vBMD by 14.1 ± 19.7 mg/cm³ ($p < 0.001$) and showed strong correlation ($r = 0.890$, $p < 0.001$). A pronounced cranio-caudal decline in vBMD was observed across the thoracic spine (mixed-effects slope − 3.96 mg/cm³ per level, $p < 0.001$). Deming regression yielded Th(1–10) = 0.956 × Lum(Th11–L4) + 18.0, resulting in thoracic mean cut-offs of 94 mg/cm³ and 133 mg/cm³ equivalent to lumbar ACR thresholds of 80 mg/cm³ and 120 mg/cm³, respectively. Subregional thoracic cut-offs differed substantially: upper thoracic (Th1–Th4) 118/148 mg/cm³, mid thoracic (Th5–Th8) 94/132 mg/cm³, and lower thoracic (Th9–Th10) 90/132 mg/cm³.

Conclusion

Lumbar ACR QCT thresholds are not directly transferable to the thoracic spine and lead to systematic misclassification. Thoracic osteoporosis assessment requires region-specific interpretation. The proposed thoracic mean and subregional cut-offs provide a statistically robust framework for thoracic QCT classification and may improve osteoporosis evaluation and surgical decision-making in thoracic and thoracolumbar instrumentation.

Introduction

Osteoporosis is one of the most prevalent systemic skeletal disorders and represents a major global health burden due to its association with fragility fractures, disability, and increased mortality (Johnell & Kanis 2006; Schuit et al. 2004). In clinical routine, osteoporosis is traditionally diagnosed by bone mineral density (BMD) measurement using dual-energy X-ray absorptiometry (DXA), primarily at the hip and lumbar spine (Cosman et al. 2014). However, DXA provides only areal BMD and is prone to measurement bias in the presence of degenerative changes, vertebral osteophytes, and vascular calcifications, particularly in older individuals, potentially leading to inaccurate classification of bone status (Ott et al. 1997; Liu et al. 1997).

Quantitative computed tomography (QCT) has emerged as a reliable alternative by enabling three-dimensional volumetric assessment of trabecular bone mineral density (vBMD), which is less affected by degenerative alterations and provides a more direct estimate of vertebral bone quality (Link 2012; Engelke 2017). In addition, QCT can be applied opportunistically, allowing existing CT examinations obtained for trauma, degenerative spinal disorders, or oncologic staging to be repurposed for bone assessment without additional radiation exposure or patient burden (Lenchik et al. 2018). Given the growing relevance of osteoporosis in spine surgery, accurate regional assessment of vertebral bone quality is increasingly important for preoperative planning, implant selection, and decision-making regarding cement augmentation or alternative fixation strategies.

Currently, diagnostic thresholds for QCT-based osteoporosis classification are defined by the American College of Radiology (ACR) and apply to the lumbar spine (Th11–L4), with established cut-offs of < 80 mg/cm³ for osteoporosis and 80–120 mg/cm³ for osteopenia (ACR 2018). Despite their widespread use, these lumbar reference values are frequently extrapolated to the thoracic spine, although thoracic vertebrae differ substantially in anatomy, loading conditions, and biomechanical environment. Previous studies have demonstrated that thoracic trabecular bone density is physiologically higher than lumbar vBMD (Budoff et al. 2012; Mao et al. 2017), suggesting that direct application of lumbar thresholds may lead to systematic misclassification. Recent work by Cheneymann et al. proposed thoracic-specific cut-off values derived from linear conversion models, supporting the concept that region-specific thresholds are required for accurate assessment of thoracic bone density (Cheneymann et al., 2024). However, the thoracic spine itself is not a homogeneous compartment. Vertebral bone density varies along the cranio-caudal axis, and the thoracolumbar junction represents a biomechanically unique transition zone with a particularly high incidence of osteoporotic vertebral fractures. Consequently, osteoporosis classification based on a single thoracic reference value may fail to account for relevant segmental differences within the thoracic region.

Therefore, the aim of the present study was to investigate whether established lumbar QCT thresholds can be applied to the thoracic spine without introducing systematic classification error. We further sought to derive thoracic-specific cut-off values by statistically translating the established ACR lumbar thresholds to thoracic vBMD measurements using Deming regression. In addition to a mean thoracic

reference (Th1–Th10), we performed a subregional analysis of the upper (Th1–Th4), mid (Th5–Th8), and lower thoracic spine (Th9–Th10) to account for segmental variability. We hypothesized that (1) thoracic vBMD is systematically higher than lumbar vBMD despite strong interregional correlation, (2) lumbar ACR thresholds lead to misclassification when applied to thoracic measurements, and (3) region- and subregion-specific thoracic cut-offs provide a more appropriate framework for thoracic osteoporosis assessment.

Materials and Methods

Study Design and Patient Selection

This retrospective single-center study included patients who underwent computed tomography (CT) of the thoracolumbar spine between June 2017 and June 2018 at a tertiary university hospital. Inclusion criteria were CT examinations covering both the thoracic and lumbar spine. Examinations with incomplete coverage of the thoracolumbar region were excluded.

A total of 227 patients were included (113 women, 114 men). Mean age was 66 ± 16 years (range 20–92 years). All data were anonymized prior to analysis. The study was conducted in accordance with institutional and ethical standards.

CT Acquisition Protocol

All CT examinations were performed without intravenous contrast using a Siemens SOMATOM Definition AS+ scanner (Siemens Healthineers, Erlangen, Germany). Scans were acquired using standardized clinical protocols. Tube voltage was 120 kVp or 80 kVp depending on patient body habitus. Images were reconstructed with a slice thickness of 1.0 mm and an increment of 0.75–1.0 mm using standard reconstruction kernels.

Long-term scanner stability was ensured by regular asynchronous calibration every six weeks using a Mindways Solid 3 phantom (Mindways Software Inc., Austin, TX, USA).

QCT-Based Volumetric Bone Mineral Density Assessment

Volumetric bone mineral density (vBMD) was assessed using QCT Pro software (Mindways Software Inc., Austin, TX, USA). Trabecular vBMD measurements were obtained using the CliniQCT module, which automatically positioned an elliptical region of interest (ROI) within the trabecular compartment of each vertebral body. All ROIs were visually inspected and manually adjusted if required. ROIs were placed approximately 1 mm within the cortical margin to exclude cortical bone and to avoid inclusion of osteophytes, endplate sclerosis, focal lesions, or artifacts.

Vertebrae affected by fracture, osteolysis, severe degenerative destruction, or major imaging artifacts were excluded from analysis. vBMD values were recorded for each evaluable vertebral body from Th1 to L5 and expressed in mg/cm³.

Definition of Thoracic and Lumbar Regions

Thoracic vBMD was defined as the mean of all evaluable vertebrae from Th1 to Th10. Due to their inclusion in the established ACR QCT classification scheme and their anatomical proximity to the lumbar spine, vertebrae Th11 and Th12 were assigned to the lumbar region. Lumbar vBMD was therefore defined as the mean of Th11 to L4. The number of thoracic vertebrae contributing to the thoracic mean varied depending on scan coverage.

Thoracic Subregional Analysis

To account for physiological variation within the thoracic spine, additional subregional thoracic vBMD values were calculated:

- **Upper thoracic spine**: Th1–Th4
- **Mid thoracic spine**: Th5–Th8
- **Lower thoracic spine**: Th9–Th10

Subregional means were calculated using all evaluable vertebrae within the respective segment.

DXA Assessment

In a subset of patients, dual-energy X-ray absorptiometry (DXA) examinations of the lumbar spine were available. DXA was performed using a GE Lunar iDXA system (GE Healthcare, USA). Areal BMD values (g/cm²) and corresponding T-scores for L1–L4 were extracted from the clinical reports. DXA results were used for descriptive comparison only and were not considered a reference standard for threshold derivation.

Classification According to ACR QCT Thresholds

For comparative purposes, QCT measurements were classified using the ACR practice parameter thresholds for spinal QCT:

- **Normal**: >120 mg/cm³
- **Osteopenia**: 80–120 mg/cm³
- **Osteoporosis**: <80 mg/cm³

Although these thresholds were originally defined for the lumbar spine (Th11–L4), they were intentionally applied to thoracic measurements to quantify classification discordance and to evaluate whether lumbar cut-offs are transferable to the thoracic spine.

Derivation of Thoracic-Specific Cut-Off Values

Thoracic-specific cut-off values were derived by statistically translating the established ACR lumbar thresholds (80 mg/cm³ and 120 mg/cm³) into thoracic equivalents. Because both lumbar and thoracic vBMD measurements represent quantitative variables subject to measurement error, Deming regression was used as an errors-in-variables method-comparison model. Deming regression was performed assuming equal error variances for lumbar and thoracic measurements ($\lambda = 1$).

Deming regression was performed for:

1. Mean thoracic vBMD (Th1–Th10) versus lumbar vBMD (Th11–L4)
2. Upper thoracic vBMD (Th1–Th4) versus lumbar vBMD (Th11–L4)
3. Mid thoracic vBMD (Th5–Th8) versus lumbar vBMD (Th11–L4)
4. Lower thoracic vBMD (Th9–Th10) versus lumbar vBMD (Th11–L4)

Thoracic cut-offs equivalent to lumbar values of 80 mg/cm³ and 120 mg/cm³ were calculated by inserting these lumbar thresholds into the respective Deming regression equations.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (version 25, IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation (SD). Differences between thoracic and lumbar mean vBMD were assessed using paired t-tests. Correlations were quantified using Pearson's correlation coefficient.

To evaluate segmental variation within the thoracic spine (Th1–Th10), the association between vertebral level and vBMD was assessed using a linear mixed-effects model with vertebral level as a fixed effect and patient as a random intercept to account for repeated measurements within individuals.

All tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

Results

Patient Characteristics

A total of 227 patients were included in this retrospective analysis. All participants underwent CT examinations covering both the thoracic and lumbar spine. The mean age was 66 ± 16 years (range 20–92 years); 113 patients were female and 114 male. Complete evaluable measurements for both thoracic

(Th1–Th10) and lumbar (Th11–L4) mean vBMD were available in 101 patients. Thoracic vBMD was calculated as the mean of all evaluable vertebrae Th1–Th10, whereas Th11 and Th12 were assigned to the lumbar region in accordance with the ACR QCT classification scheme. Lumbar vBMD was defined as the mean of Th11–L4.

Thoracic vs Lumbar vBMD

Mean volumetric bone mineral density (vBMD) was 102.5 ± 44.1 mg/cm³ in the thoracic spine and 85.1 ± 44.6 mg/cm³ in the lumbar spine. In patients with evaluable measurements in both regions (N = 101), thoracic vBMD values were consistently higher than lumbar values, with a mean paired difference of 14.1 ± 19.7 mg/cm³ ($p < 0.001$). Thoracic and lumbar vBMD were strongly correlated ($r = 0.890$, $p < 0.001$), indicating a stable interregional relationship despite a systematic offset.

Segmental Distribution and Thoracic Gradient

On a segmental level, vBMD demonstrated a pronounced cranio-caudal gradient along the thoracolumbar spine, with highest values in the upper thoracic region and a marked decline toward the thoracolumbar junction and lumbar spine (Fig. 1). Within the thoracic spine (Th1–Th10), vBMD decreased significantly with caudal vertebral level. A linear mixed-effects model (patient as random intercept) confirmed a significant decline of approximately − 3.96 mg/cm³ per thoracic level ($p < 0.001$).

Deming-Derived Thoracic Mean Cut-Off Values (Th1–Th10)

To derive thoracic-specific QCT thresholds equivalent to established lumbar ACR cut-offs, Deming regression was performed using lumbar mean vBMD (Th11–L4) as the reference region. Deming regression yielded the relationship:

Th(1–10) **= 0.956 × Lum(Th11–L4) + 18.0** (N = 101)

Based on this model, lumbar ACR thresholds of 80 mg/cm³ and 120 mg/cm³ corresponded to thoracic mean values of **94.4 mg/cm³** and **132.7 mg/cm³**, respectively. Thus, Deming-derived thoracic mean thresholds were defined as < 94 mg/cm³ for osteoporosis and > 133 mg/cm³ for normal bone density, with intermediate values classified as osteopenic.

Subregional Thoracic Cut-Off Values

Subregional analyses demonstrated that the thoracic spine cannot be considered a homogeneous compartment. Deming-based translation of lumbar ACR thresholds resulted in markedly different cut-offs for the upper, mid, and lower thoracic spine. In the upper thoracic spine (Th1–Th4), equivalent thresholds were substantially higher (118/148 mg/cm³) compared to the mid thoracic spine (Th5–Th8: 94/132 mg/cm³) and the lower thoracic spine (Th9–Th10: 90/132 mg/cm³). All Deming-derived thoracic cut-off values are summarized in Table 1.

Table 1

Thoracic osteoporosis thresholds were derived by translating the established ACR lumbar reference values (80 and 120 mg/cm³; reference region Th11–L4) into thoracic equivalents using Deming regression. Cut-offs are provided for mean thoracic vBMD and thoracic subregions. Values are given in mg/cm³. Rounded values are provided for clinical interpretability.

Thoracic region	Vertebral levels	N	Osteoporosis cut-off (equiv. Lum < 80)	Normal cut-off (equiv. Lum ≥ 120)
Mean thoracic	Th1–Th10	101	94	133
Upper thoracic	Th1–Th4	101	118	148
Mid thoracic	Th5–Th8	101	94	132
Lower thoracic	Th9–Th10	101	90	132

Classification According to ACR Thresholds

Applying the original ACR lumbar thresholds directly to thoracic measurements resulted in substantial discrepancies in osteoporosis classification. For this analysis, mean regional vBMD values were dichotomized as osteoporotic (< 80 mg/cm³) versus non-osteoporotic (≥ 80 mg/cm³). Patient classification was performed in the subset with complete paired thoracic and lumbar measurements (N = 101). Using the ACR osteoporosis cut-off of 80 mg/cm³, 33 patients were classified as osteoporotic based on mean thoracic vBMD (Th1–Th10), whereas 47 patients were classified as osteoporotic based on mean lumbar vBMD (Th11–L4) (Table 2).

Table 2

Discordant osteoporosis classification (< 80 mg/cm³) when applying lumbar ACR thresholds to mean thoracic vBMD (Th1–Th10) versus mean lumbar vBMD (Th11–L4) in patients with complete paired measurements (N = 101). The table illustrates region-dependent misclassification, with a higher proportion of osteoporosis classification based on lumbar measurements.

Classification pattern	Thoracic (Th1–Th10)	Lumbar (Th11–L4)	Patients (n)	Proportion (%)
Concordant osteoporotic	< 80	< 80	32	31.7
Concordant non-osteoporotic	≥ 80	≥ 80	53	52.5
Discordant (lumbar osteoporotic only)	≥ 80	< 80	15	14.9
Discordant (thoracic osteoporotic only)	< 80	≥ 80	1	1.0
Total			101	100

When thoracic and lumbar classifications were compared within the same patients, 32 patients were classified as osteoporotic in both regions and 53 patients as non-osteoporotic in both. A discordant classification pattern was observed in 15 cases (14.9%), with non-osteoporotic thoracic vBMD (≥ 80

mg/cm³) but osteoporotic lumbar vBMD (< 80 mg/cm³). Only one patient (1.0%) showed the inverse constellation.

Vertebral-Level Discordance

On a vertebral level, 41 patients (33.9%) demonstrated a discordant distribution pattern, defined as at least one thoracic vertebra (Th1–Th10) with vBMD above 80 mg/cm³ and at least one lumbar vertebra (Th11–L4) with vBMD below 80 mg/cm³. This segment-based definition captures within-patient heterogeneity and therefore results in higher discordance rates compared to mean-based regional classification. The mean age of this subgroup was 65.3 ± 9.8 years. Mean thoracic vBMD in these cases was 103.4 ± 22.1 mg/cm³, whereas the corresponding lumbar mean was significantly lower at 68.5 ± 14.6 mg/cm³ ($p < 0.001$), indicating that localized bone loss predominantly affects the thoracolumbar transition zone while thoracic segments frequently remain above lumbar osteoporosis thresholds.

DXA Subgroup

DXA examinations were available in a limited subset of patients and were analyzed descriptively. Due to the small sample size, DXA data were not used for threshold derivation.

Discussion

The present study demonstrates that thoracic and lumbar volumetric bone mineral density (vBMD) values, although strongly correlated, are separated by a systematic and clinically relevant regional offset. In our cohort of 227 patients, mean thoracic vBMD was 102.5 ± 44.1 mg/cm³ compared with 85.1 ± 44.6 mg/cm³ in the lumbar spine. In the paired subset with evaluable measurements in both regions (N = 101), thoracic vBMD exceeded lumbar vBMD by 14.1 ± 19.7 mg/cm³ ($p < 0.001$) despite a very strong interregional correlation ($r = 0.890$; $p < 0.001$). These findings indicate that thoracic and lumbar vertebrae represent biologically and biomechanically distinct bone compartments rather than interchangeable measurement sites.

With the aging of the population and the rising incidence of osteoporotic vertebral fractures, preoperative planning prior to spinal instrumentation has become increasingly relevant. In the treatment of unstable osteoporosis-related fractures, trabecular bone mineral density represents a key determinant of fixation strength, as higher trabecular BMD is directly associated with increased pedicle screw anchorage and reduced rates of implant failure in posterior spinal stabilization (Halvorson et al., 1994; Wu et al., 2012; Weiser et al., 2017). Consequently, the definition of a reliable threshold for osteoporotic bone quality is essential to enable accurate risk stratification and to guide surgical decision-making.

The consequences of this regional offset become evident when lumbar ACR QCT thresholds are applied to the thoracic spine (ACR, 2018). Using the ACR cut-off of 80 mg/cm³ in the paired subset (N = 101), osteoporosis was classified in 47 patients based on mean lumbar vBMD but in only 33 patients based on mean thoracic vBMD. Thus, osteoporosis was classified considerably more frequently based on lumbar measurements, despite the strong correlation between regions. This discrepancy reflects systematic

regional misclassification rather than measurement variability and indicates that lumbar ACR thresholds are not directly transferable to thoracic QCT measurements, as they fail to account for the physiologically higher thoracic vBMD.

This discordance was particularly pronounced at the thoracolumbar transition zone. On a vertebral level, 41 patients (33.9%) demonstrated a discordant pattern, defined as at least one thoracic vertebra (Th1–Th10) with vBMD ≥ 80 mg/cm³ and at least one vertebra within Th11–L4 with vBMD < 80 mg/cm³. In these patients, mean thoracic vBMD remained 103.4 ± 22.1 mg/cm³, whereas mean lumbar vBMD was significantly lower at 68.5 ± 14.6 mg/cm³ ($p < 0.001$). This finding suggests that bone loss may occur predominantly in the thoracolumbar transition zone, while upper and mid-thoracic segments frequently remain above osteoporotic thresholds. Notably, this region represents both a biomechanical transition zone and a common site of osteoporotic vertebral fractures and construct-related complications, underscoring the clinical relevance of the observed thoracic–lumbar discordance.

These findings are consistent with prior quantitative imaging studies. Mao et al. reported higher thoracic than lumbar trabecular density in healthy adults (Mao et al., 2017), and Lenchik et al. demonstrated that thoracic QCT measurements are both technically robust and strongly correlated with lumbar values (Lenchik et al., 2004). More recent opportunistic CT studies by Pickhardt et al. and Graffy et al. further showed that vertebral attenuation varies systematically along the spine, with higher baseline values in the thoracic region (Pickhardt et al., 2013; Graffy et al., 2017). Importantly, QCT precision, reproducibility, and accuracy have been shown to be comparable between thoracic and lumbar vertebrae (Budoff et al., 2010; Wong et al., 2005), and the strong correlation observed in our cohort ($r = 0.890$) together with a stable absolute offset supports a true biological difference rather than a technical artifact.

From a biomechanical perspective, the observed regional differences are expected. The thoracic spine is integrated into the rib cage and subjected to different loading conditions than the lumbar spine, which serves as the primary weight-bearing segment. Classical biomechanical models have shown that lumbar vertebrae achieve structural stability through larger vertebral bodies and disc geometry, allowing sufficient load bearing at lower trabecular density (Panjabi and White, 1980). Finite element and cadaveric studies further demonstrate that vertebral failure strength depends not only on density but also on geometry and microarchitecture, both of which differ systematically between thoracic and lumbar levels (Buckley et al., 2007; Fields, 2010). In this context, the consistently higher thoracic vBMD observed in our cohort likely represents an adaptive response to different load distribution and stabilization requirements rather than a pathological difference.

Importantly, higher thoracic vBMD does not necessarily translate into superior mechanical fixation. Coe et al. showed earlier pedicle screw failure in thoracic compared with lumbar vertebrae despite higher bone density (Coe et al., 1990). More recent studies by Schwaiger et al. confirmed that pedicle morphology, cortical thickness, and screw trajectory contribute more to fixation stability than trabecular density alone (Schwaiger et al., 2014). These biomechanical considerations reinforce that density-based thresholds must be interpreted in a region-specific context.

From a clinical standpoint, these findings have direct implications for surgical planning. QCT-based bone assessment is increasingly used to guide implant selection, cement augmentation, and risk stratification. Weiser et al. and Shirley et al. demonstrated that CT-based bone metrics predict screw loosening, vertebral fractures, and construct failure (Weiser et al., 2017; Shirley et al., 2020). However, applying lumbar-derived thresholds to thoracic measurements introduces a clinically relevant classification bias and may result in inappropriate decision-making regarding cement augmentation or fixation strategy when thoracic or thoracolumbar levels are instrumented. In practical terms, this means that surgical planning based on lumbar QCT thresholds alone may lead to inappropriate augmentation strategies or implant selection when instrumentation involves the thoracic or thoracolumbar spine.

Our data therefore support the development of thoracic-specific QCT reference values. Mathematical conversion models, such as those proposed by Cheneymann et al., represent a useful first step, but they cannot replace outcome-based validation (Cheneymann et al., 2024). Ultimately, thoracic thresholds should be derived from associations with vertebral fracture risk, implant failure, and biomechanical strength. The proposed thoracic cut-offs should be interpreted as a pragmatic translation of established lumbar ACR criteria and provide a clinically applicable framework; however, prospective outcome-based validation is required before definitive clinical implementation.

This study has limitations. Its retrospective design may introduce selection bias, and fracture outcomes were not available for all patients, precluding direct outcome-based validation of thoracic-specific thresholds. In addition, thoracic scan coverage varied between patients, although all available thoracic vertebrae were included to preserve regional representativeness. Despite these limitations, the consistency of the observed thoracic–lumbar offset and its agreement with prior literature support the robustness of the findings.

In conclusion, thoracic QCT measurements cannot be interpreted using established lumbar ACR thresholds without introducing clinically relevant misclassification. Thoracic vBMD is systematically higher than lumbar vBMD despite strong interregional correlation, and pronounced segmental variation exists within the thoracic spine. Using Deming regression, we provide thoracic mean and subregional cut-off values as a statistically robust translation of established lumbar criteria. These region-specific thresholds may improve osteoporosis assessment and preoperative decision-making in thoracic and thoracolumbar spinal instrumentation. Future prospective studies are required to validate these cut-offs against clinically meaningful outcomes such as vertebral fracture risk, pedicle screw loosening, and construct failure.

Declarations

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Clinical trial number

Clinical trial number: not applicable.

Human Ethics and Consent to Participate declarations

This retrospective study was approved by the local ethics committee of the University Medical Center Göttingen, Germany (application number: 8/11/17). The study was conducted in accordance with institutional and ethical standards. All data were anonymized prior to analysis. Due to the retrospective nature of the study and the use of anonymized data, the requirement for informed consent was waived.

Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contribution

F.S.K. and L.W. conceived and designed the study. F.S.K. performed QCT measurements and data collection. F.S.K. and L.W. performed the statistical analysis. F.S.K. drafted the manuscript. K.J., H.A.M., J.R., and M.-P.M. contributed to data interpretation and revised the manuscript. W.L. and L.W. supervised the study. All authors read and approved the final manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and institutional regulations but are available from the corresponding author on reasonable request.

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Figures

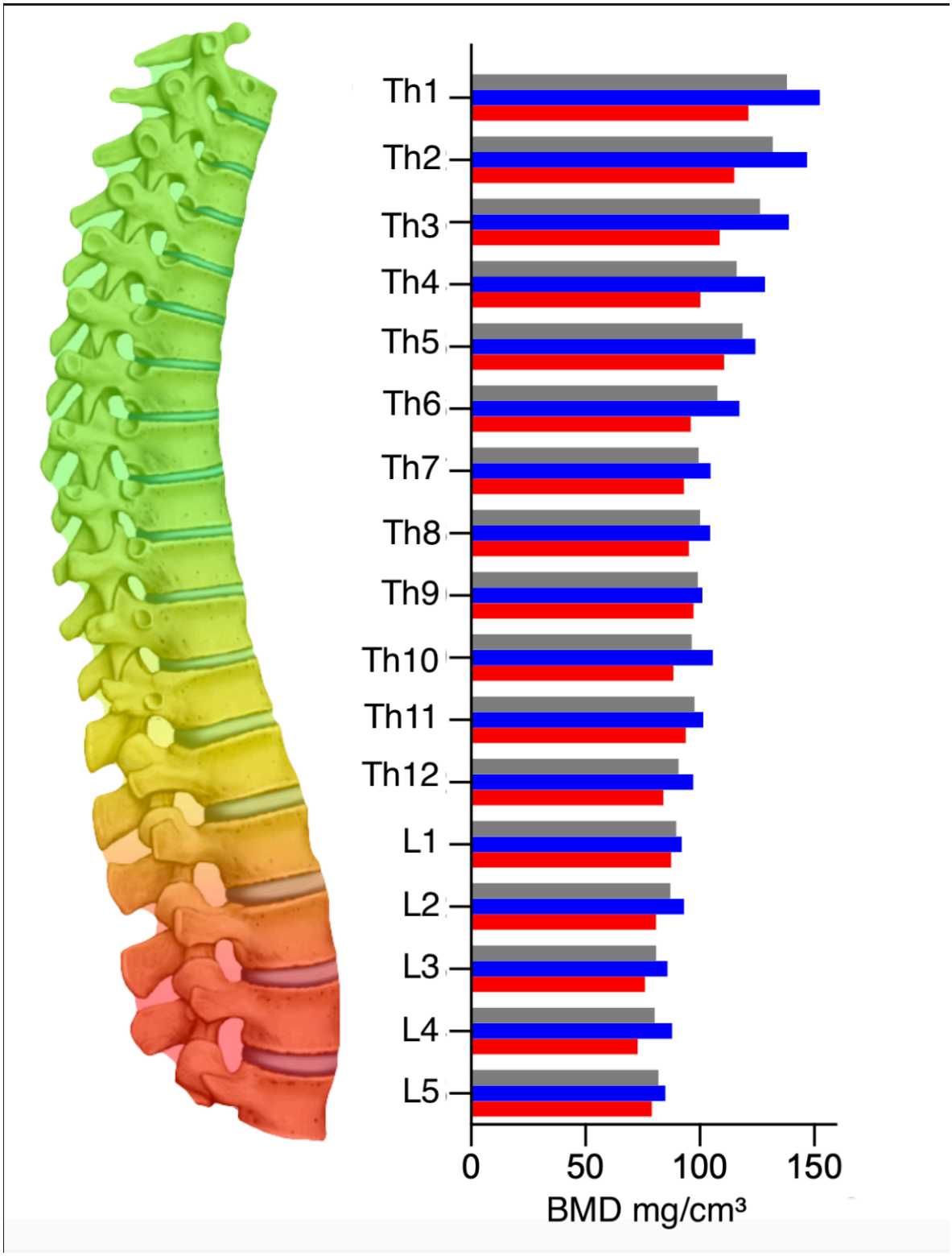


Figure 1

Segmental distribution of volumetric bone mineral density (vBMD) along the thoracolumbar spine. The 3D color-coded rendering (left) and bar chart (right) demonstrate a pronounced cranio-caudal decline in trabecular vBMD from Th1 to L5. vBMD is highest in the upper and mid-thoracic spine and decreases markedly at the thoracolumbar junction (Th11–L2), resulting in systematically lower values in the lumbar region.