Spine–Hip BMD Discordance and Age-Dependent Divergence Between T-Scores and Z-Scores at DXA: A Cross-Sectional Study

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ABSTRACT

Background: Spine–hip bone mineral density (BMD) discordance complicates dual-energy X-ray absorptiometry (DXA) interpretation and may affect osteoporosis classification. This study assessed the prevalence of spine–hip discordance and the age-dependent divergence between T-scores and Z-scores.

Methods: This cross-sectional study included 292 apparently healthy individuals who underwent DXA. BMD, T-scores, and Z-scores were analyzed at the lumbar spine, left femur, and right femur. Spine–hip discordance was defined as an absolute difference of at least 1.0 SD between the lumbar spine T-score and either femoral T-score and was categorized as minor (1.0 to <2.0 SD) or major (≥2.0 SD). The T–Z gap was defined as T-score minus Z-score. Inter-site differences were assessed using repeated-measures ANOVA, and associations between age and T–Z gap were evaluated using Pearson correlation.

Results: Participants were predominantly female (84.9%). The lumbar spine showed the lowest score profile, with mean T-scores of −1.36 ± 1.64 at the lumbar spine, −0.08 ± 1.16 at the left femur, and −0.17 ± 1.27 at the right femur. Corresponding mean Z-scores were −0.19 ± 1.62, 0.57 ± 1.10, and 0.48 ± 1.20, respectively (all inter-site comparisons, $p < 0.001$). Overall, 73.3% of subjects demonstrated spine–hip discordance, including 41.1% with minor and 32.2% with major discordance. Age was strongly negatively correlated with the T–Z gap at all sites ($r = −0.892$, −0.886, and −0.888; all $p < 0.001$). Osteoporosis prevalence increased from 3.1% by hip-only classification to 29.1% by worst-site classification.

Conclusion: Spine–hip discordance is highly prevalent, predominantly spine-driven, and associated with substantial age-related T/Z divergence and diagnostic reclassification.

Keywords: Bone mineral density; Dual-energy X-ray absorptiometry; Spine–hip discordance; T-score; Z-score; Osteoporosis; Lumbar spine; Hip BMD.

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INTRODUCTION

Osteoporosis is a systemic skeletal disorder defined by low bone mass and impaired microarchitecture, increasing fracture risk (1). Dual-energy X-ray absorptiometry (DXA) remains the gold standard for measuring bone mineral density (BMD) and is widely used for diagnosis and risk stratification. According to World Health Organization (WHO) criteria, osteoporosis is defined by a T-score ≤ −2.5, with diagnosis based on the lowest value among measured skeletal sites (2, 3). However, a well-recognized limitation of DXA-based assessment is the occurrence of inter-site diagnostic discordance, where different skeletal regions yield different diagnostic categories (normal, osteopenia, or osteoporosis). This phenomenon is particularly observed between the lumbar spine and proximal femur and can significantly influence clinical decision-making (4, 9). Discordance is typically categorized as minor or major depending on whether the discrepancy spans adjacent or non-adjacent diagnostic categories (4).

Previous studies have demonstrated that spine–hip discordance is common, affecting approximately 34–50% of patients, with major discordance occurring in a smaller but clinically important subset (4, 8). The underlying mechanisms are multifactorial, including age-related degenerative changes, differences in trabecular versus cortical bone composition, and technical or biological factors affecting regional bone loss (5, 9). Furthermore, discordance has important clinical implications, as it may alter fracture risk estimation and treatment strategies, particularly when relying on single-site assessment tools such as FRAX (3).

In addition to inter-site discordance, emerging attention has been directed toward discrepancies between T-scores and Z-scores, reflecting differences between young-adult reference comparisons and age-matched norms. These differences may provide additional insight into age-related bone changes and diagnostic interpretation yet remain underexplored in routine clinical practice.

Any discordance was present in 58.8% of subjects aged <40 years, 66.7% in those aged 40–49 years, 81.4% in those aged 50–59 years, 72.4% in those aged 60–69 years, and 73.7% in those aged ≥70 years. Major discordance was most frequent in the 50–59-year group (40.2%) and remained common thereafter. Sex-stratified analysis showed a higher prevalence of any discordance among women than men (75.8% vs. 59.1%). Major discordance was also more common in women (35.9%) than in men (11.4%).

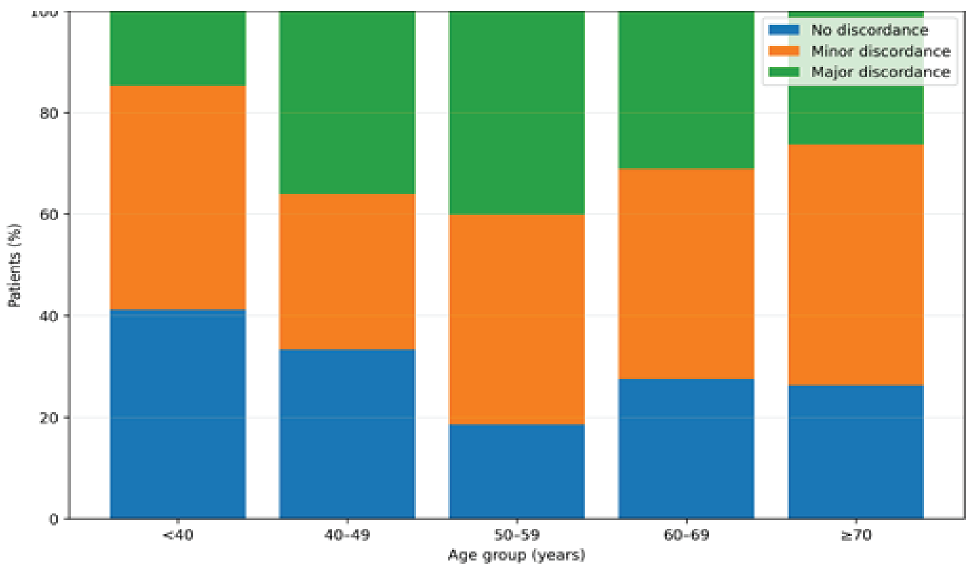

Figure 2. Stacked bar chart illustrating the proportion of subjects with no discordance, minor discordance (1.0-1.9 SD), and major discordance (≥2.0 SD) across predefined age groups.

Age-dependent divergence between T-scores and Z-scores

A strong negative linear relationship was observed between age and the T-Z gap at all skeletal sites. Pearson correlation coefficients were r = -0.892 for the lumbar spine, r = -0.886 for the left femur, and r = -0.888 for the right femur (all $p < 0.001$). Figure 3 shows these associations with fitted regression lines and 95% confidence bands. The widening negative T-Z gap with advancing age indicates that T-scores become progressively more negative relative to Z-scores over the lifespan. This effect was most pronounced at the lumbar spine, where the average divergence was greatest.

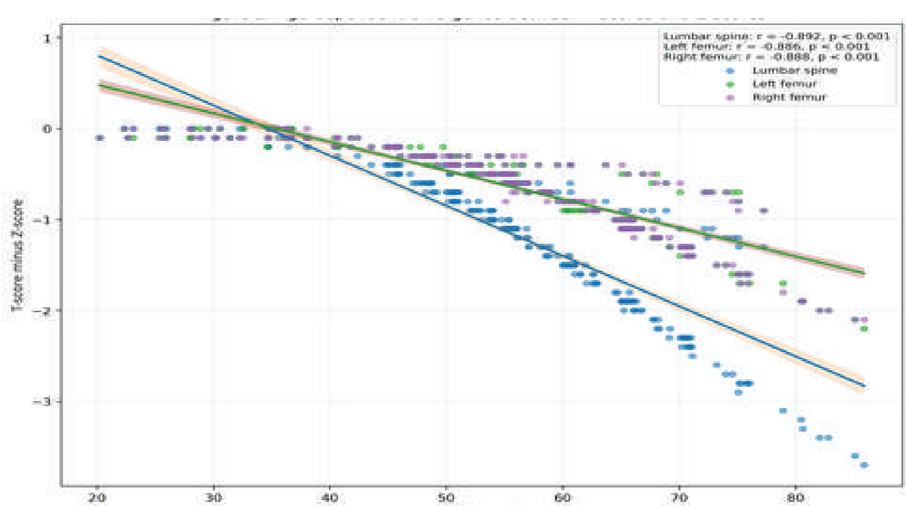

Figure 3. Age-dependent divergence between T-scores and Z-scores Scatter plots depicting a strong negative correlation across all sites (lumbar spine r = -0.892, left femur r = -0.886, right femur r = -0.888; all p < 0.001), indicating progressive widening of the T-Z gap with advancing age.

Impact on WHO diagnostic classification

When classification was based on the lowest femoral T-score only, 212/292 (72.6%) subjects were classified as normal, 71/292 (24.3%) as osteopenic, and only 9/292 (3.1%) as osteoporotic. In contrast, when the lowest T-score across all three measured sites was used, the distribution changed substantially to 108/292 (37.0%) normal, 99/292 (33.9%) osteopenic, and 85/292 (29.1%) osteoporotic. Thus, inclusion of lumbar spine measurements resulted in marked upward diagnostic reclassification. Among subjects considered normal on hip-only assessment, 71 were reclassified as osteopenic and 33 as osteoporotic after incorporation of lumbar spine data. Among those classified as osteopenic by hip-only assessment, 43 were reclassified as osteoporotic when worst-site classification was applied. These shifts are shown in Figure 4.

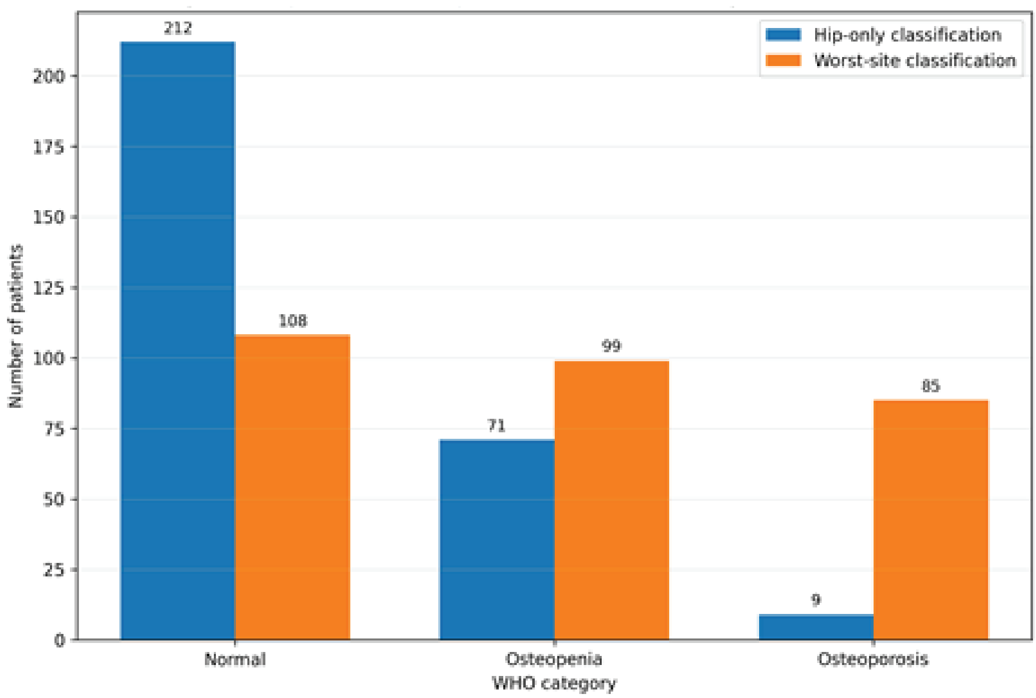

Figure 4. Grouped bar chart comparing WHO diagnostic classification based on hip-only T-scores (lowest of left or right femur) versus worst-site T-scores (lowest of lumbar spine or femoral sites).

DISCUSSION

The study demonstrated a high prevalence of spine–hip BMD discordance, with a clear predominance of lower lumbar spine T-scores compared with femoral sites, along with a significant age-dependent divergence between T-scores and Z-scores. These findings reinforce the complexity of DXA interpretation and highlight the limitations of relying on a single skeletal site or metric for osteoporosis diagnosis.

The observed pattern of discordance is consistent with the WHO recommendation that osteoporosis diagnosis should be based on the lowest T-score among measured sites, acknowledging that skeletal heterogeneity is inherent to bone loss (1). Similar to our findings, multiple studies have reported that discordance between lumbar spine and hip measurements is common in clinical practice. Mounach et al. reported a substantial prevalence of discordance between skeletal sites, emphasizing that differences in bone composition and remodeling rates contribute to this phenomenon (2, 9). In another study, authors reported that such discordance significantly affects fracture risk estimation using FRAX, particularly when lumbar spine values are disproportionately lower than femoral measurements (3).

Our finding that lumbar spine T-scores are more frequently reduced compared with femoral sites aligns with earlier observations that trabecular bone-rich regions, such as the spine, are more metabolically active and therefore exhibit earlier and more pronounced bone loss (4). According to Moayyeri et al., the spine is more damaged in the early stages of osteoporosis, and spine–hip discordance frequently reflects differing rates of bone loss. (4). However, this pattern of discordance is influenced largely by demographic and clinical factors, indicating discordance across different populations in both direction and magnitude (5).

The study found that the prevalence of discordance aligns with recent literature, indicating that discordance occurs in nearly half of the studied population, emphasizing its frequency and clinical significance (6). Many studies further extended this concept by demonstrating discordance not only between spine and hip but also between bilateral hips in specific patient populations, indicating that skeletal asymmetry can contribute to diagnostic variability (7). More than half of elderly patients showed discordance, particularly among those with hip fractures, highlighting its clinical significance (8). Discordance was associated with an increased risk of hip fracture, particularly when femoral BMD was lower than spinal BMD, highlighting the need for careful site selection in clinical decision-making.

Discordance is influenced by multiple factors, including age, body composition, and technical aspects of measurement, reinforcing that it is a multifactorial phenomenon rather than a measurement artifact (9). A similarly high prevalence of discordance in a tertiary care setting attributed partly to referral bias and the inclusion of symptomatic patients, a factor that may also contribute to the relatively high discordance observed in the present study (10). Chiang et al. further identified age as a significant determinant of discordance, particularly for major discordance, which increased with advancing age (11).

A key novel finding of the present study is the demonstration of a significant divergence between T-scores and Z-scores, particularly at the lumbar spine, with this divergence increasing with age. While previous studies have primarily focused on inter-site discordance, limited attention has been given to discrepancies between these two diagnostic metrics. The observed widening of the T–Z gap with age can be explained by the difference in reference populations, as T-scores compare patients to young healthy adults, whereas Z-scores account for age-matched norms. With aging, the decline in bone density relative to young adults becomes more pronounced than when compared to age-matched populations, leading to increasing divergence between these two indices. Degenerative changes in the lumbar spine, such as osteophytes, endplate sclerosis, and vascular calcifications, can artificially raise BMD measurements and affect the interpretation of Z-scores, thus exacerbating discrepancies in assessments.

The clinical implications of these findings are significant. Discordance between skeletal sites can lead to misclassification of osteoporosis status, potentially resulting in inappropriate treatment decisions if only a single site is considered. Moreover, divergence between T-scores and Z-scores may provide additional insight into age-related bone changes and should not be overlooked in clinical interpretation. As demonstrated in previous studies, discordance can influence fracture risk prediction and may necessitate a more individualized approach to patient management (3,8).

Overall, the findings of this study are consistent with existing literature in confirming the high prevalence and clinical relevance of spine–hip discordance, while also extending current knowledge by highlighting the importance of T–Z score divergence as an additional dimension of diagnostic variability. These results support the need for comprehensive, multi-site, and multi-metric assessment of BMD to improve diagnostic accuracy and optimize patient care in osteoporosis management.

CONCLUSION

The study revealed that spine–hip BMD discordance is common and largely influenced by lower lumbar spine T-scores. This cohort exhibited a notably high discordance burden compared to previous research. Additionally, there was a significant age-related divergence between T-scores and Z-scores at all skeletal sites, especially the lumbar spine. These results advocate for the routine use of multi-site DXA data and suggest that evaluating T-scores and Z-scores concurrently, especially at the lumbar spine, could improve clinical assessments in older adults.

LIMITATIONS

This study has several limitations. First, the cross-sectional design does not allow assessment of longitudinal change or fracture outcomes. Second, the cohort was derived from a single-center referral population and was predominantly female, which may limit generalizability. Third, degenerative lumbar changes were not quantified independently, so their contribution to discordance could not be fully assessed. Finally, FRAX and incident fractures were not directly analyzed, limiting correlation of discordance with future fracture risk.

CONFLICT OF INTEREST

The authors have no financial, personal, or professional conflicts that could inappropriately bias this work.

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