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One-third Radius bone mineral density measurement utility in the diagnosis of osteoporosis: a comparative analysis with femoral and lumbar spine bone mineral density

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ABSTRACT

Osteoporosis is defined by a BMD ≤ 2.5 SD below the young adult reference population. Standard dual-energy X-ray absorptiometry (DXA) scans for osteoporosis involve the femoral neck and lumbar spine, but alternative sites like the one-third radius (1/3 R) are only used when these sites are inaccessible. This study assessed the correlation and level of agreement between BMD at the 1/3 R, femoral neck, and lumbar spine to evaluate its diagnostic utility. Data from 43,801 patients referred for DXA scans in northwest England were analysed. Of these, 437 underwent 1/3 R scans. Demographic comparisons between patients with and without forearm scans were conducted. The primary analysis included patients with scans at the 1/3 R, lumbar spine, and bilateral femoral regions;($n = 183$). Spearman's correlation assessed BMD relationships, Cohen's kappa analysed osteoporosis classification agreement, and Bland-Altman plots evaluated measurement bias. The cohort had a mean age of 65.7 years (SD 12.9), with 83.3% female and 41.2% reporting fractures. Patients who underwent 1/3 R scans ($n = 437$) were older, heavier, and had a higher body mass index (BMI). Correlation analysis showed only moderate associations between 1/3 R and femoral/lumbar spine BMD ; ($r = 0.29$ to 0.36, $p < 0.001$). Cohen's kappa demonstrated only slight agreement for 1/3 R, femoral neck and lumbar spine T-scores ($\kappa = 0.14$–0.29). Bland-Altman analysis revealed that 1/3 R scans systematically underestimated BMD relative to femoral and lumbar sites, with mean biases of −0.7 for femoral sites and −1.53 for lumbar spine. The 1/3 R BMD showed poor agreement and systematic underestimation compared to central sites, limiting its reliability for osteoporosis diagnosis. Future research should explore alternative peripheral weight-bearing sites and novel diagnostic technologies to assess BMD where central sites cannot be scanned.

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1. Introduction

The World Health Organisation defines osteoporosis as a bone mineral density (BMD) 2.5 standard deviations below that of a young, healthy adult, typically assessed via dual-energy X-ray absorptiometry (DXA) at the femoral neck [1,2]. Osteoporosis is a massive public health concern as it costs the National Health Service (NHS) approximately £4.4bn annually and is associated with increased morbidity and mortality, with the number of fragility fractures set to increase as the population ages [3,4]. Despite its high prevalence, osteoporosis remains underdiagnosed worldwide, including in the UK [5]. Limited accessibility to DXA scans, often requiring outpatient appointments, restrict the number of patients who are screened for osteoporosis, contributing to its underdiagnosis [6].

Currently, most patients receive bilateral femoral and lumbar spine DXA scans, as these sites are considered gold standard for assessing bone mineral density. When central DXA measurements are not possible, the International Society for Clinical Densitometry (ISCD) recommends the one-third radius (later referred to as 1/3 R) region as an alternative site for BMD assessment [7]. One-third radius scans are typically reserved for patients for whom femoral or lumbar spine scans cannot be performed, such as individuals with severe obesity (where their weight exceeds the DXA table limit), those with hyperparathyroidism, or cases where lumbar spine and/or femoral scans are uninterpretable [8]. Consequently, forearm BMD assessment are of limited use in routine clinical practice, despite studies indicating that 1/3 R BMD measurements, particularly at the 1/3 R, can correlate with femoral BMD and may have potential for broader diagnostic application [9,10].

Many studies suggest a weak positive association between bone mineral density (BMD) at the 1/3 R and that at the hip and lumbar spine [11,12]. However,

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these studies often have relatively small sample sizes, limiting the generalizability of their conclusions. Despite this limitation, evidence suggests that the 1/3 R site remains clinically relevant due to its predominantly cortical composition, which aligns more closely with the femoral neck than the ultra-1/3 R [8]. Given ISCD's endorsement of the 1/3 R region, further research is necessary to clarify its diagnostic reliability and fracture prediction ability compared to central DXA sites [9].

2. Aims

This study aimed to assess the diagnosis utility of the 1/3 R by evaluating its correlation and agreement with femoral neck and lumbar spine measurements, using a large retrospective dataset.

3. Methods

3.1. Study design and data collection

This retrospective cross-sectional study included patients referred from primary and secondary care to a DXA scanning facility in Northwest England between June 2004 and January 2024. At each visit, the patient's height and weight were first recorded and used to calculate the body mass index (BMI). Next the patient's clinical history was ascertained by a trained technician and entered into a data collection form. The data collection form was designed to capture demographic information, FRAX risk factors, and fragility fracture history including the location of fracture. Fragility fractures were defined as fractures occurring as a result of low impact trauma that would not ordinarily cause fragility fractures, which were collected for the 2 years preceding the scan. All data were cross checked against the patients' medical records to ensure accuracy.

Most patients underwent DXA scans of both the lumbar spine and bilateral femoral regions, while a subset also had scans at the 1/3 R site. The specific indication for a 1/3 R scan was not recorded in our dataset. Data were stored in a Microsoft Access relational database and extracted for statistical analysis.

Full ethical approval for pseudonymized data extraction in the absence of informed consent was obtained from the regional NHS Research Ethics Committee Northwest Preston (project number 14/NW/1136).

3.2. Demographic characteristics

Demographic characteristics, baseline variables, and OP risk factors were compared between patients who underwent 1/3 R scans and those who did not, to identify potential differences between the groups. Continuous variables were analysed using Student's t-test, and categorical variables were assessed with Pearson's chi-squared test. A significance threshold of $p < 0.05$ was applied to all comparisons.

3.3. Statistical analyses

The primary analysis included all patients who underwent bone density scans at all three sites: the lumbar spine, bilateral hips, and 1/3 R. This excluded patients with missing bone density data at any of the said sites. To quantify the relationships between bone density measurements at these sites, a Spearman's correlation matrix was constructed, providing an overview of the strength and direction of associations.

However, as correlation measurements does not assess how well measurements agree, a Bland-Altman analysis was performed to evaluate the agreement between bone density measurements across the sites. This method was used to identify systematic differences, such as whether any site consistently over- or underestimated BMD compared to others. Comparisons were conducted for T-scores across the 1/3 R, left femur, right femur, and lumbar spine. Assumptions of normality between the mean differences at site were assessed and met prior to conducting the Bland-Altman analysis.

Furthermore, given the clinical importance of bone density measurements in classifying patients into categories such as normal BMD (T-score ≥ -1.0), osteopenia (T-score between -1.0 and -2.5), and osteoporosis (T-score ≤ -2.5), categorical BMD classifications were coded for all three sites. To evaluate the consistency of classification across sites, Cohen's kappa statistics were calculated to measure the level of agreement between sites in categorizing patients into these ranges. Statistical analysis was conducted using RStudio, with the following packages utilized: tidyverse, corrplot, and blandr.

4. Results

4.1. Demographics

Of the 43,801 patients referred for scans, the mean age was 65.7 years (SD 12.9), and 83.3% ($n = 36{,}480$) were female. Overall, 41.2% ($n = 18{,}037$) reported a fragility fracture. Mean height was 162.3 cm (SD 8.6), weight 71.6 kg (SD 16.6), and BMI 27.1 kg/m^2 (SD 5.7).

Patients undergoing 1/3 R scans ($n = 437$, 1.0%) were older (67.4 vs. 65.7 years, $p = 0.005$) and had higher mean weight (75.1 vs. 71.6 kg, $p < 0.001$) and BMI (28.3 kg/m^2 vs. 27.1 kg/m^2, $p < 0.001$) compared to non-scanned patients ($n = 43{,}364$, 99.0%). There

was a statistically significant difference in gender distribution between the scanned and non-scanned groups ($p < 0.001$), although the actual difference in female proportion was minimal (82.8% vs. 83.2%). No significant differences in height were observed (162.7 vs. 162.3 cm, $p = 0.370$).

One-third radius-scanned patients reported higher alcohol consumption (>3 units/day, 9.6% vs. 7.0%, $p = 0.033$) and lower smoking rates (3.9% vs. 10.2%, $p < 0.001$). They also had a significantly higher prevalence of rheumatoid arthritis (38.7% vs. 6.1%, $p < 0.001$) and were more likely to report a family history of fractures (24.7% vs. 20.3%, $p = 0.024$). Rates of hyperparathyroidism (2.5% vs. 1.7%, $p = 0.170$) and glucocorticoid use (5.0% vs. 9.6%, $p = 0.001$) were low in both groups, with no differences in personal fracture history (5.0% vs. 5.1%, $p = 0.943$) or overall fracture reporting (37.8% vs. 41.2%, $p = 0.144$).

DXA outcomes showed 1/3 R-scanned patients had lower left femoral T-scores higher right femoral T-scores and higher L1-L4 T-scores; full details can be seen in Table 1.

4.2. Primary analyses

One hundred and eighty-three patients who underwent scans at all three site (bilateral femur, lumbar spine and 1/3 R) were included in the primary analysis. Spearman's rank correlation showed a strong correlation between left and right femoral T-scores ($r = 0.73$), and weaker correlations between 1/3 R and both the left femur ($r = 0.36$), right femur ($r = 0.30$) and the lumbar spine ($r = 0.29$) which were all statistically significant ($p < 0.001$). These results are presented in Figure 1.

The Cohen's Kappa analysis revealed varying levels of inter-rater agreement between osteoporosis classifications based on different anatomical sites. Moderate agreement was observed between the left and right femoral T-scores ($k = 0.47$, $p < 0.001$) as would be expected. Only slight agreement was observed between the 1/3 R and the left femur ($k = 0.14$, $p = 0.003$), right femur ($k = 0.17$, $p < 0.001$) and the lumbar spine ($k = 0.2$, $p < 0.001$). These results can be seen in Table 2.

The Bland-Altman analysis for the 1/3 R, left femoral, right femoral, and lumbar spine T-scores showed the following: For the 1/3 R vs. right femoral T-score (Figure 2(a)), the mean bias was −0.67, indicating underestimation by the 1/3 R T-score, with limits of agreement (LoA) between −4.13 and 2.78. The 1/3 R vs. left femoral T-score (Figure 2(b)) showed a mean bias of −0.70 and LoA between −4.12 and 2.73, also underestimating the left femoral T-score. For the 1/3 R vs. lumbar spine T-score (Figure 2(c)), the mean bias was −1.53, with LoA from −5.44 to 2.38, indicating a more substantial underestimation. All comparisons were statistically significant ($p < 0.001$), with wide LoA indicating considerable variability across anatomical sites.

For reference, the left vs. right femoral T-scores (Figure 2(d)) showed a minimal bias of 0.025 ($p = 0.7071$), with LoA ranging from −1.73 to 1.77, indicating high agreement between the two methods.

5. Discussion

Our findings indicate that 1/3 R bone mineral density (BMD) measurements are limited in their reliability as a diagnostic alternative to femoral neck and lumbar

Table 1. Comparison of baseline demographics between patients who have underwent a 1/3 R scan and those who have not.

	1/3R scanned (n = 437; 1.0%)	1/3R not scanned (n = 43,364; 99.0%)	P
Demographics :			
Gender (n = 36,480 females, 83.2%)	392 (F),82.8%	36,088 (F),83.2%	<0.001
Age (years)	67.4 (13.3)	65.7 (12.9)	0.005
Height (cm)	162.7 (8.4)	162.3 (8.6)	0.370
Weight (kg)	75.1 (18.9)	71.6 (16.6)	<0.001
Body Mass Index (kg/m^2)	28.3 (6.4)	27.1 (5.6)	<0.001
Lifestyle factors:			
Alcohol use* (>3 units per day) (n = 3076; 7.0%)	42 (9.6%)	3,034 (7.0%)	0.033
Current smoker (n = 4431; n%)	17 (3.9%)	4,414 (10.2%)	<0.001
Medical History:			
Rheumatoid arthritis (n = 2,808; 6.4%)	169 (38.7%)	2,639 (6.1%)	<0.001
Hyperparathyroidism (n = 736; 1.7%)	11 (2.5%)	724 (1.7%)	0.170
Glucocorticoid use (n = 4,175, 9.5%)	22(5.0%)	4,153(9.6%)	0.001
Personal history of a fracture (n = 2,238; 5.1%)	22 (5.0%)	2,216 (5.1%)	0.943
Family history of a fracture (n = 8,933; 20.4%)	108 (24.7%)	8,825 (20.3%)	0.024
Reported a fragility fracture* (n = 18,037; 41.2%)	165 (37.8%)	17,872 (41.2%)	0.144
DXA Outcomes:			
Left femoral T-score	−0.98 (1.3)	−0.73 (1.3)	0.002
Right femoral T-score	−0.73 (1.2)	−0.99 (1.3)	<0.001
L1-L4 T-score	0.33 (1.8)	−0.5 (1.8)	<0.001

Key: data presented as n(%) or mean(SD).
*Reported a fragility fracture: defined as self-report low-trauma or fragility fracture occurring within 2 years of the DXA scan.

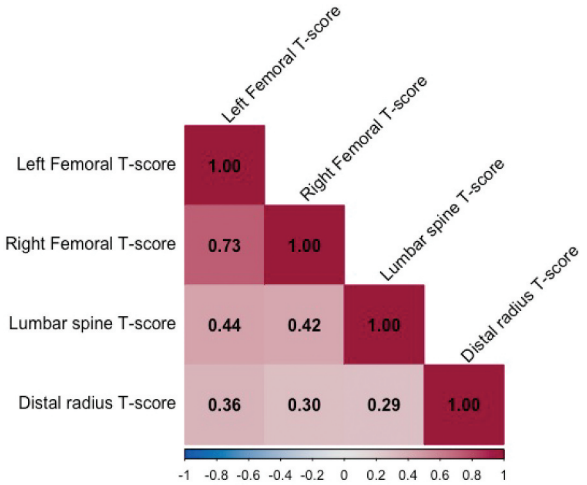

Figure 1. Correlation matrix. Spearman's correlation matrix of T-scores across anatomical sites. Darker red indicates stronger positive correlations; lighter shades represent weaker correlations. The colour gradient rangers from −1 (blue) to +1 (dark red).

spine assessments. Specifically, 1/3 R scans exhibited weak correlation, poor agreement, and a systematic tendency to underestimate BMD values when compared with central weight-bearing sites.

Bland-Altman analysis highlighted this underestimation, with a mean bias of −0.7 for femoral sites and −1.53 for lumbar spine BMD, alongside wide limits of agreement. These results point to significant variability and a consistent tendency for 1/3 R measurements to underrepresent BMD. Correlation analyses further supported this, showing only moderate associations between 1/3 R and femoral neck BMD, while correlations with lumbar spine BMD were even weaker. These findings suggest that 1/3 R scans fail to consistently reflect systemic bone health, especially at sites more clinically relevant for diagnosing osteoporosis.

Agreement analyses reinforced these conclusions. Cohen's kappa values demonstrated slight to fair agreement when diagnosing osteoporosis between 1/3 R and central sites, with $\kappa = 0.14–0.20$ across comparisons. In contrast, agreement between left and right femoral neck measurements was much stronger ($\kappa = 0.47$), highlighting the superior reliability of weight-bearing sites. The low agreement for 1/3 R scans underscores their potential to misclassify osteoporosis status. Combined, these analyses suggest that 1/3 R measurements are not a robust alternative for assessing BMD and may lead to underdiagnosis or misclassification of osteoporosis.

Our results challenge the conclusions of several prior studies that have advocated for the use of the 1/3 R as an alternative site for BMD measurement. For example, studies by Eftekhar-Sadat et al. and Abdelmohsen et al. reported stronger correlations between 1/3 R and other skeletal sites, suggesting 1/3 R as a viable diagnostic tool for osteoporosis when central sites were inaccessible [13,14]. However, these studies were limited by smaller sample sizes and less comprehensive statistical methodologies. In contrast,

Table 2. Kappas Cohen analysis.

	Left femoral T-score	Right femoral T-score	Lumbar spine T-score	1/3R T-score
Left femoral T-score				
Right femoral T-score	AG: 73.2% EA: 49.0% K: 0.47 P: <0.001			
Lumbar spine T-score	AG: 60.7% EA: 54.2 K: 0.14 P: 0.013	AG: 67.8% EA: 54.6% K: 0.29 P: <0.001		
1/3R T-score	AG: 48.1% EA: 39.6% K: 0.14 P: 0.003	AG: 49.7% EA: 39.6% K: 0.17 P: <0.001	AG :54.1% EA: 42.4% K: 0.20 P<0.001	

Key: AG = actual agreement, EA = expected agreement, K = kappa statistic and p = p-value.
Colour coding: K <0 (no agreement)= red, 0–0.2 (slight agreement) = light red, 0.21–0.4 (fair to moderate) = orange, 0.41–0.6 (moderate to substantial) = yellow, 0.61–0.8 (strong) = light green and 0.81–1 (strong to perfect) = green.

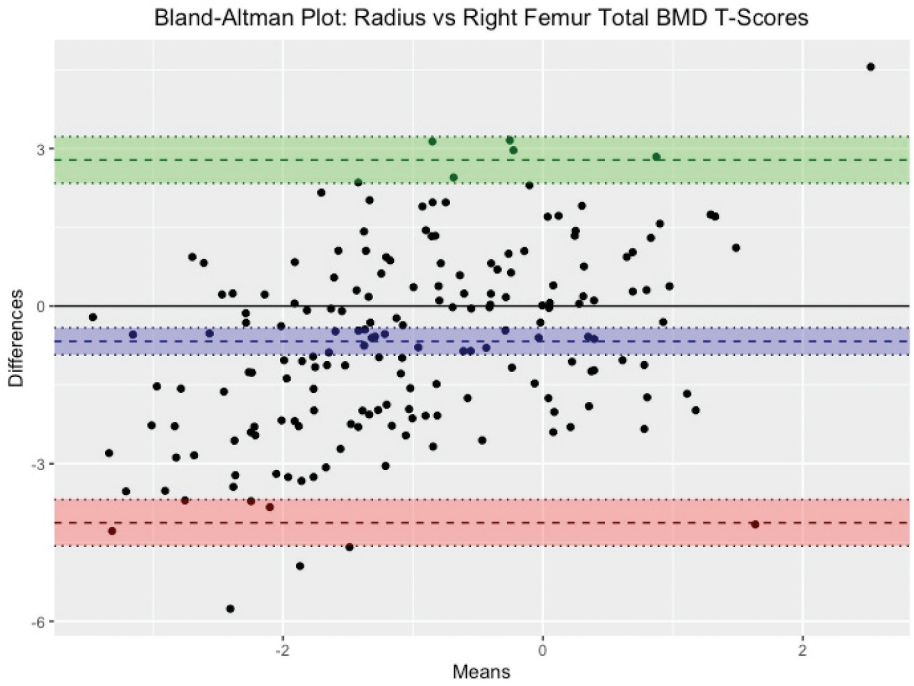

Figure 2a. Bland Altman plot between the BMD measured at the right femur and the 1/3R.

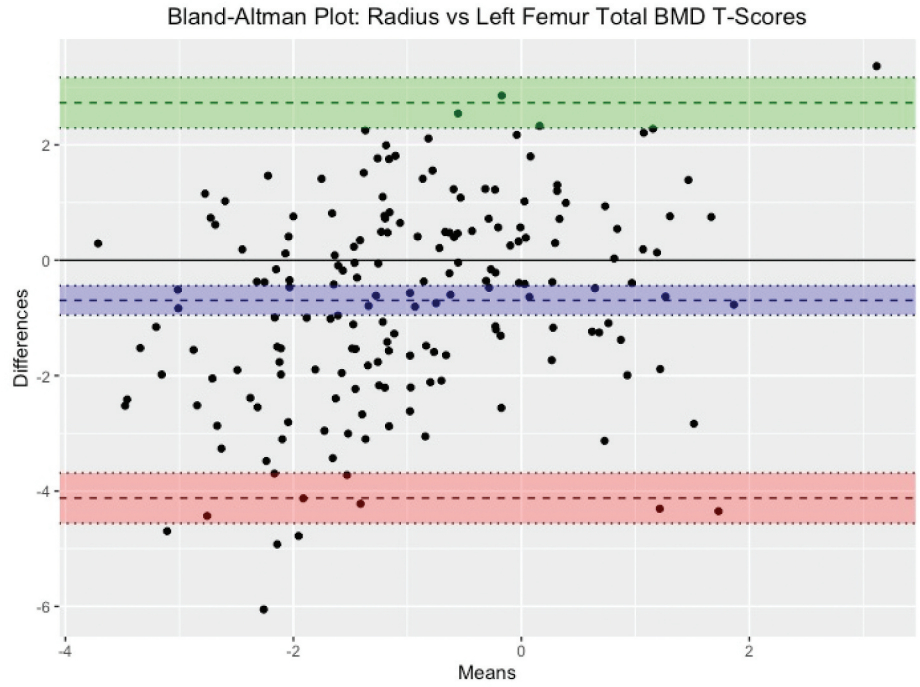

Figure 2b. Bland Altman plot between the BMD measured at the left femur and the 1/3R.

our study employed a substantially larger dataset and robust analyses including Spearman's correlation, Cohen's kappa, and Bland-Altman analysis to provide a more rigorous evaluation.

Our findings demonstrated that 1/3 R scans consistently underestimated BMD compared to central sites, with Bland-Altman analysis showing mean biases of −0.7 for femoral neck and −1.53 for lumbar spine BMD. Prior studies may have overlooked these systematic biases due to narrower statistical approaches and smaller sample sizes. For instance, Ma et al. emphasized the potential of 1/3 R scans for predicting fractures but overlooked the significant underestimation of BMD values observed in our study [15]. Similarly, Rhee et al. highlighted a correlation between systemic and 1/3 R subchondral BMD but primarily focused on subchondral bone properties, rather than the overall reliability of 1/3 R scans for osteoporosis diagnosis [11].

The variability and poor agreement demonstrated in our analyses highlight the need for caution when interpreting 1/3 R measurements.

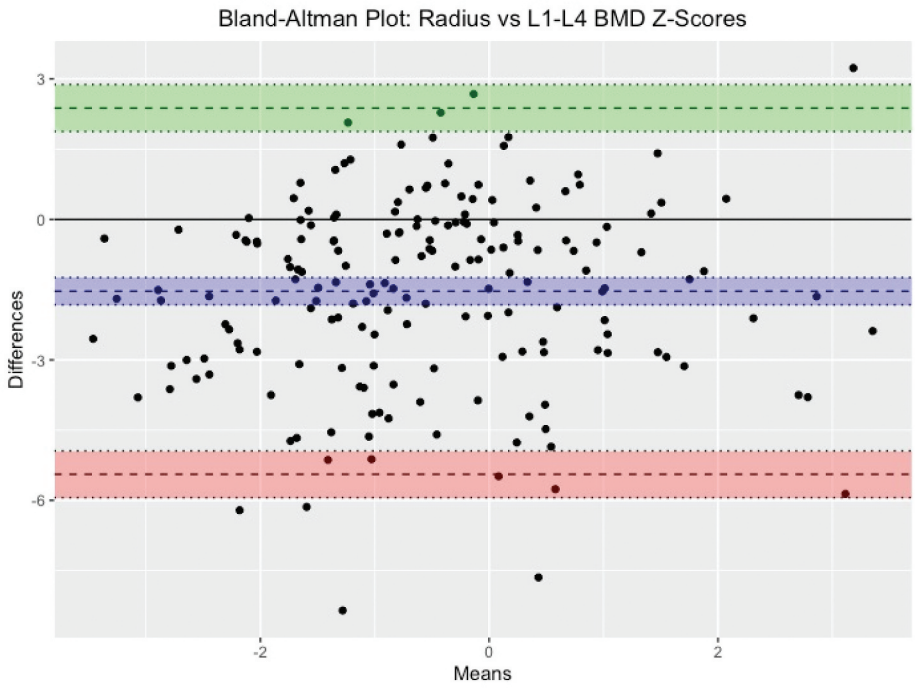

Figure 2c. Bland Altman plot between the BMD measured at the lumbar spine and the 1/3R.

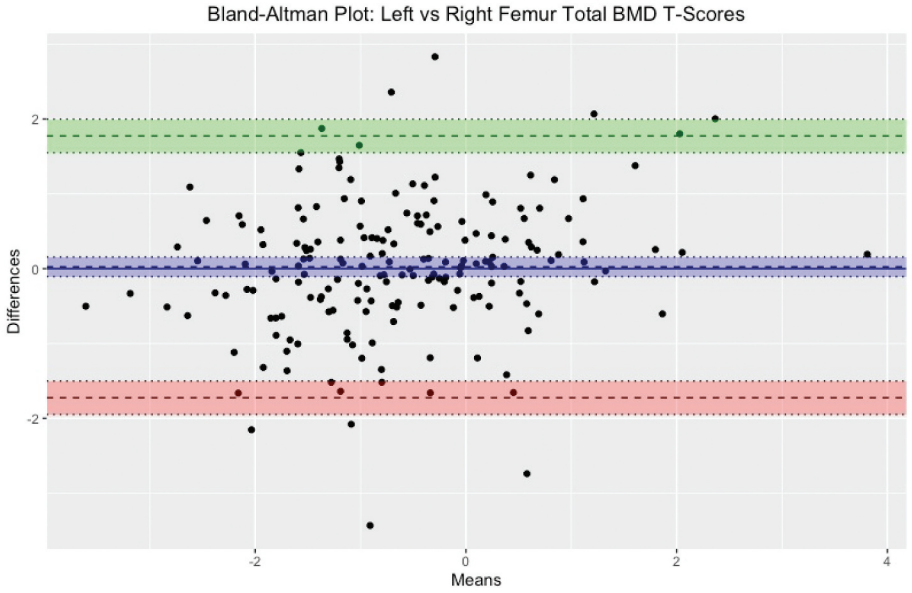

Figure 2d. Bland Altman plot between the BMD measured at the left and right femurs for comparison.

Cohen's kappa values between 1/3 R and central sites were slight to fair (κ = 0.14–0.20), far lower than the agreement observed between femoral neck measurements (κ = 0.47). While earlier studies, such as Azami et al., advocated for 1/3 R scans in specific contexts, such as when central sites are inaccessible, our findings suggested that use in these very limited scenarios while currently justified may not be ideal due to bone density underestimation [16]. Hence, given that the 1/3 R underestimates bone density when compared to the gold standard femoral scans further research should investigate whether alternative sites which could offer more reliable estimation of bone density.

One of the reasons that the 1/3 R should not be routinely used for BMD measurement in osteoporosis diagnosis may be due to the 1/3 R not being a weight bearing site. Given this it is less affected by the biomechanical forces that influence bone remodelling in weight-bearing areas. Hence peripheral sites which are easily accessible and weight bearing such as such as the calcaneus or proximal tibia could offer more reliable estimation of bone density given mechanical loading and should be

investigated further to determine whether they should be routinely recommended instead of 1/3 R scans.

Looking forward, alternative measurement sites with better alignment to systemic bone health should be prioritized. Technologies like opportunistic computed tomography (oCT) and quantitative computed tomography (qCT), as discussed by Deshpande et al. [17], show significant potential in providing accurate BMD assessments without the limitations inherent to DXA or 1/3 R scan including the need got outpatient appointments. The study by Wong et al. highlights that thoracic qCT, with its high precision and strong correlation to lumbar spine BMD, could serve as a valuable tool in osteoporosis assessment, especially when systemic imaging is already employed for other purposes [18]. Raman spectroscopy, although in its early stages, offers promising potential as a non-invasive method for evaluating bone composition and mineral density, further expanding the arsenal of diagnostic tools available [19]. Exploration of weight-bearing peripheral sites, such as the calcaneus or proximal tibia, could also yield viable diagnostic tools. Advanced imaging techniques like MRI-derived vertebral bone quality (VBQ) scores and CT-based attenuation measures, as noted in the Deshpande review, should be investigated further to standardize their application and integrate them into routine practice [17].

Future research should focus on understanding the biomechanical and anatomical factors influencing BMD measurement reliability across different sites. This includes validating emerging imaging techniques and identifying optimal diagnostic thresholds that align with systemic bone health and fracture risk. Such efforts could refine diagnostic strategies and provide new opportunities for early detection and management of osteoporosis.

6. Conclusion

In conclusion, our study highlighted significant limitations in the use of 1/3 R bone mineral density (BMD) measurements as a diagnostic alternative to central weight-bearing sites such as the femoral neck and lumbar spine. The 1/3 R BMD values exhibited weak correlation and poor agreement with central sites, consistently underestimating BMD, thereby undermining its reliability for osteoporosis diagnosis. While prior research has suggested 1/3 R as a viable alternative in certain clinical contexts, our findings, based on a larger dataset and more robust statistical analyses, reveal diagnostic shortcomings that caution against its routine use outside of these limited indications. Further research is needed to investigate alternative weight bearing sites, including the tibia and calcaneus, which may serve as accessible and clinically viable options for assessing bone health.

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Data availability statement

Data can be made available upon reasonable request to the corresponding author

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