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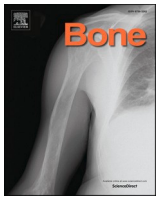

Full Length Article

Side-to-side differences in hip bone mineral density in patients with unilateral hip osteoarthritis

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ABSTRACT

Background: Accurately evaluating bone mineral density (BMD) in patients with unilateral hip osteoarthritis (OA) is crucial for diagnosing osteoporosis and selecting implants for hip arthroplasty. Our goal was to measure the BMD differences between sides, examine contributing factors, and identify the optimal side for BMD assessment in these patients.

Methods: We analyzed 108 women with unilateral hip OA. Bilateral hip BMD was assessed automatically through quantitative CT (QCT) utilizing a validated, deep-learning-based approach. We evaluated BMD variations between the OA and healthy hips across total, neck, and distal regions. To determine their contributions, we analyzed factors, including patient demographics, Crowe classification, Bombelli classification, knee OA status, hip functional score, and gluteal muscle volume and density. Furthermore, we examined how side-to-side BMD differences influenced osteoporosis diagnosis using T-scores based on QCT.

Results: The average BMD on the OA side was 6.9 % lower in the total region, 14.5 % higher in the neck region, and 9.4 % lower in the distal region than on the healthy side. Contributing factors to the reduced BMD in the OA hip included younger age, Bombelli classification (atrophic type), and significant gluteal muscle atrophy. Diagnoses from the OA side revealed lower sensitivity (61 %) than those from the healthy side (88 %).

Conclusions: Analysis on one side alone yields a more precise osteoporosis diagnosis from the healthy side. Nonetheless, bilateral BMD assessment remains crucial, particularly in younger individuals and those with atrophic OA types. Although based on QCT, our findings support bilateral analysis by dual-energy X-ray absorptiometry for these patients.

1. Introduction

Osteoporosis is typically diagnosed by assessing the bone mineral density (BMD) of the lumbar spine and hip with dual-energy X-ray absorptiometry (DXA) [1–4]. Guidelines and studies recommend measuring the hip's BMD on a single side (i.e., left or right) because the superiority of bilateral measurement has yet to be widely accepted. This is largely due to the strong correlation between the left and right femur in control subjects and the time and cost involved in acquiring and analyzing DXA images, which are crucial in clinical practice settings.

Assessing hip BMD before surgery is crucial for patients with hip osteoarthritis (OA) undergoing hip arthroplasty. This evaluation aids in choosing the appropriate type of stem implant—cemented or cementless—to ensure adequate fixation and favorable outcomes and improve osteoporosis treatment, if required, to prevent complications such as periprosthetic fractures [5,6]. Despite some studies reporting side-to-side BMD differences in unilateral hip OA patients using DXA, there is still a lack of research on this topic. Reportedly, 26 %–36 % of patients with hip OA undergoing hip arthroplasty have unilateral hip OA [7]; however, the best location for these DXA measurements (i.e., taken from the affected, unaffected, or both sides) remains unclear [8,9]. Insufficient information exists, and challenges hinder the precise measurement

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of hip BMD through DXA in patients with unilateral OA. Notably, the anatomical variations in the femur affected by OA [10] are often attributed to the BMD measurement. Further, pain and osteophytes in OA hips interfere with the hip's internal rotation [11]. These factors are crucial for an accurate BMD measurement to compensate for femoral anteversion in the DXA measurements.

We previously developed and validated an automated method that uses deep learning to measure hip BMD from quantitative CT images [12,13], which could account for inevitable errors in DXA measurements [14,15]. In this study, we sought to 1) measure the differences in side-to-side BMD in the hip for individuals with unilateral hip OA using quantitative CT images, 2) identify the factors that lead to these BMD discrepancies, and 3) determine which hip side should be examined to diagnose osteoporosis in patients with unilateral hip OA accurately.

2. Materials and methods

Ethical approval was granted by the Institutional Review Board of both participating institutions (A and B) for this retrospective study. The study initially involved 156 consecutive women who underwent total hip arthroplasty due to unilateral hip OA at these institutions. The diagnosis of unilateral hip OA was performed by a board-certificated orthopaedic surgeon based on an anteroposterior radiograph with Kellgren–Lawrence (KL) classification [16] of $\geq$3 and $\leq$ 1 for the OA and healthy sides, respectively. These patients underwent preoperative hip CT imaging (OptimaCT660 scanner, GE Healthcare Japan, Tokyo, Japan) and DXA images of the lumbar region (Institution A: Discovery A, Hologic Japan, Tokyo, Japan, Institution B: PRODIGY, GE Healthcare, Japan). Institution A routinely conducted DXA analysis of the hip, unlike Institution B. From these 156 cases, we excluded patients with any form of pain or absence of pain data in the healthy hip (34 cases), noticeable deformation of the femur (6 cases), prior surgery or fracture of the hip (4 cases), prior lumbar surgery (3 cases), and hemiparesis (1 case). This left 108 cases available for inclusion.

2.1. CT acquisition

CT images were obtained from the pelvis to the knee using a calibration phantom (B-MAS200, Kyoto Kagaku, Kyoto, Japan) positioned beneath the patient. The imaging was conducted at a tube voltage of 120 kVP, a tube current of 89.9 (58.8–110.2) mA, and a table height of 149.6 $\pm$ 11.3 mm. The pixel size was (0.703–0.820 mm) $\times$ (0.703–0.820 mm), and the slice thickness was 1.25 mm. Images were reconstructed using filtered back projection with a standard kernel applied.

2.2. BMD measurement from quantitative CT images

BMD quantification from CT images was automatically conducted using a previously developed and validated deep-learning-based method, demonstrating a correlation coefficient of 0.94 with the DXA measurements [13]. In summary, a pre-trained deep-learning model automatically selected the volume of the femur (Fig. 1a) and identified nine landmarks: the head center; four points at the head-neck junction; the neck center; the tip of the lesser trochanter; and two points on the femoral shaft, located 2 and 5 cm distal to the lesser trochanter [13,17] (Fig. 1b). Next, the femur volume was rotated along the coronal, sagittal, and axial planes into a neutral position to account for femoral anteversion and the patient's orientation during CT image acquisition (Fig. 1b). The adjusted images were then projected onto the anteroposterior plane, creating a digitally reconstructed radiograph that was calibrated with a calibration phantom [18] (Fig. 1c). BMD was measured for three areas; the total region (referred to as CT-aBMD), the neck region (CT-aBMD(neck)), and the area distal to the lesser trochanter (CT-aBMD(dist.)). BMD values were compared between the OA and healthy sides, with the decrease from the healthy side calculated for the OA side in g/cm^2 and as percentages (with low and high BMD on the OA side recorded as positive and negative values, respectively). Additionally, the cases in which the absolute side-to-side percentage BMD difference surpassed the least significant change (LSC) outlined in the International Society for Clinical Densitometry (ISCD) guidelines were documented: 5.0 % for the total region and 6.9 % for the neck region [19]. All measurements were conducted utilizing MATLAB (v9.8, The MathWorks,

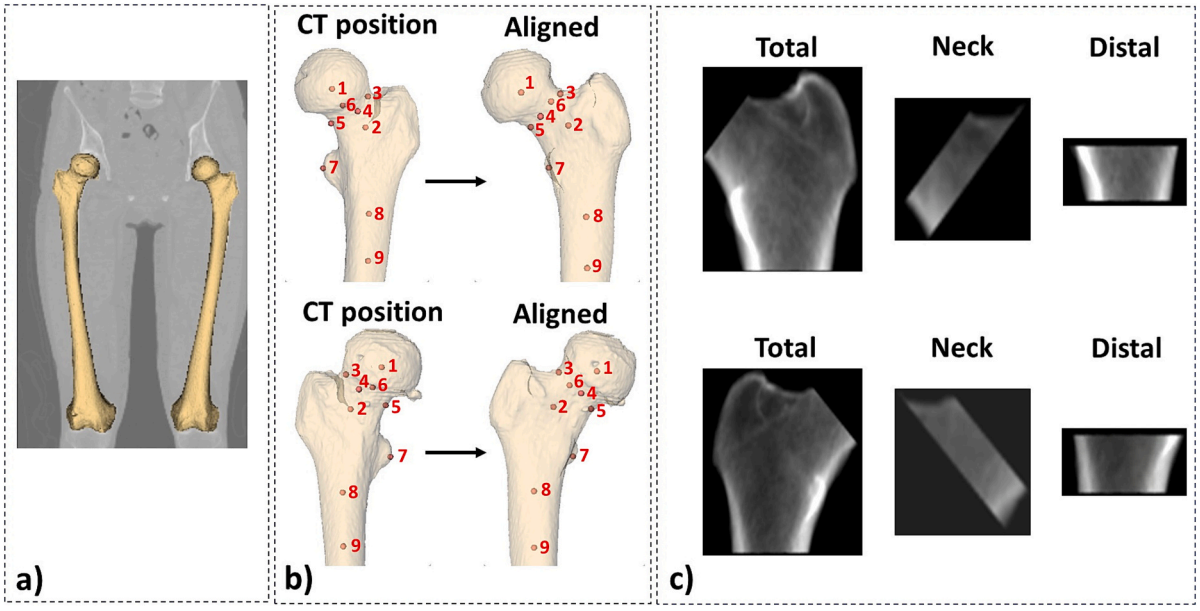

Fig. 1. The process for measuring the BMD in the total, neck, and distal regions for a case of unilateral hip OA (right side). (a) Bilateral femurs are extracted from the CT images. (b) Nine landmarks are identified: 1. head center; 2. neck center; 3. superior head-neck junction; 4. anterior head-neck junction; 5. inferior head-neck junction; 6. posterior head-neck junction; 7. lesser trochanter; 8. 2-cm distal from the lesser trochanter; and 9. 5-cm distal from the lesser trochanter. The femur volume is rotated to the neutral position (right). (c) The aligned femur volume is projected onto the coronal plane to measure BMD in the total region (CT-aBMD), neck region (CT-aBMD(neck)), and distal region (CT-aBMD(dist.)).

Natick, MA, USA).

2.3. Factor analysis

Previously identified factors influencing BMD were examined to see if they impacted the side-to-side differences in CT-aBMD and CT-aBMD (neck). In particular, the connection between CT-aBMD and CT-aBMD (neck) was analyzed with patient demographics, such as age and weight [20,21], hip function (decrease in the OA side's Japanese Orthopaedic Association (JOA) hip score [22]), and radiographic findings. The radiographic assessments included Crowe classification [23] (hip classification based on proximal migration of the femoral head, classified as I–IV), Bombelli classification [24] (hip OA classification based on the osteophyte formation, categorized as 'atrophic', 'hypertrophic', and 'normotrophic'), and knee KL classification ≥3. Furthermore, the gluteal muscles' volume and density (in Hounsfield Units: HU) were automatically quantified from CT images using a deep-learning model [25]. We assessed their side-to-side differences in the BMD discrepancy using bivariate and multivariate analyses.

2.4. Effect of side-to-side BMD differences in the diagnosis of osteoporosis

The impact of side-to-side BMD variations on osteoporosis diagnosis was evaluated in two phases. Initially, the diagnostic discrepancies were analyzed by region (regional analysis). Specifically, an osteoporosis diagnosis was determined if the T-score was ≤ −2.5, as standardized by a correction method suggested by the Japan Osteoporosis Society [1], referring to the ISCD guidelines [19] for each region established as the gold standard. Next, we assessed each side's capability to detect osteoporosis. In this phase, osteoporosis was identified in either of the four regions (total and neck regions on both sides) with a T-score of ≤−2.5. The sensitivity of detecting osteoporosis through the BMD measurements on each side was evaluated (comprehensive analysis).

2.5. Statistical analysis

The normality of the data was verified using the Anderson–Darling test. When the data was normally distributed, it was reported as mean ± standard deviations. The correlation between the two variables was evaluated with the Pearson correlation coefficient (r), and a paired *t*-test was employed for group comparisons. The values were presented as median (interquartile range: IQR) for non-normally distributed data, and Spearman's rank correlation coefficient (r_s) was used to assess correlation. Differences in BMD among the groups were examined using either the Wilcoxon rank-sum test or the Kruskal–Wallis test. A generalized linear model (GLM) was utilized to analyze factors influencing BMD differences (i.e., the OA side decrease in BMD). JMP (JMP Pro Version 19, SAS Institute Inc., Cary, NC, USA) was used for all statistical analyses, with *p*-values <0.05 deemed statistically significant.

3. Results

The patients' median (IQR) age, height, weight, and body mass index were 66 (56–74.8) years, 154.1 (149.6–158.0) cm, 53.5 (48.0–59.0) kg, and 22.7 (20.6–24.7) kg/m^2, respectively (Table 1). Seven patients were diagnosed with osteoporosis (T-score ≤ −2.5) based on the DXA measurements of the lumbar region.

3.1. Side-to-side differences for the CT-aBMD

The mean CT-aBMD values for the OA side and the healthy side showed a significant difference, measuring 0.709 ± 0.127 g/cm^2 for the OA side compared to 0.755 ± 0.132 g/cm^2 for the healthy side ($p < 0.001$) (Table 2). A correlation analysis revealed a coefficient of 0.859 ($p < 0.001$) when comparing CT-aBMD with the respective sides (Fig. 2a). The median absolute %BMD difference was 8.0 % (Table 2), with 78 cases (72 %) displaying differences exceeding the LSC.

Table 1
Patient demographics.

Parameters	Numbers
Age (years)	66 (56–74.8)
Height (cm)	154.1 (149.6–158.0)
Weight (kg)	53.5 (48.0–59.0)
BMI (kg/m^2)	22.7 (20.6–24.7)
KL classification (OA side)	Grade 3: 25 cases, Grade 4: 83 cases
Crowe classification (OA side)	Type 1: 102 cases, type 2: 6 cases
Bombelli classification (OA side)	Hypertrophic: 14 cases, normotrophic: 76 cases, atrophic: 18 cases
Knee OA	None: 101 cases, hip OA side: 3 cases, healthy side: 4 cases

Data are expressed as medians (interquartile range). KL classification, Kellgren–Lawrence classification; OA, osteoarthritis.

3.2. Side-to-side differences for the CT-aBMD(neck)

The average CT-aBMD(neck) values for the OA side and the healthy side were 0.729 ± 0.119 and 0.630 ± 0.116 g/cm^2, respectively, showing a significant difference ($p < 0.001$) (Table 2). The correlation coefficient when examined was 0.671 ($p < 0.001$) (Fig. 2b). The median absolute %BMD difference recorded was 14.8 % (Table 2), with 82 instances (76 %) where the differences were greater than the threshold LSC.

3.3. Side-to-side differences for the CT-aBMD(dist)

The CT-aBMD(dist.) on the OA side (0.866 ± 0.154 g/cm^2) was significantly lower compared to the healthy side (0.957 ± 0.152 g/cm^2) ($p < 0.001$) (Table 2). There was a strong correlation between the OA side and the healthy side, with $r = 0.838$ ($p < 0.001$) (Fig. 2c), and the median absolute %BMD difference was noted at 10.2 % (Table 2).

3.4. Factor analysis for the side-to-side difference

In the bivariate analysis, younger age, the atrophic type in the Bombelli classification, and increased gluteus %atrophy were associated with low CT-aBMD on the OA side (Table 3). Similarly, these factors, excluding gluteus %atrophy, were linked to decreased CT-aBMD(neck) on the OA side (Table 4). The multivariate analysis utilizing GLM confirmed that the significant factors identified in the bivariate analysis persisted for CT-aBMD (Table 5) and CT-aBMD(neck) (Table 6).

3.5. Effect of side-to-side BMD differences in the diagnosis of osteoporosis

3.5.1. Regional analysis

For the total region, 8 cases (7 %) of osteoporosis could go undiagnosed if only the OA side is evaluated. In comparison, 13 cases (12 %) would remain undiagnosed if only the healthy side is considered (Fig. 3a). Focusing on the neck region, there were 27 cases (25 %) where osteoporosis might not be recognized if only the OA side is assessed. Conversely, just 1 case (1 %) would be missed if the evaluation was based solely on the healthy side (Fig. 3b).

3.5.2. Comprehensive analysis

When combining the total and neck regions to diagnose osteoporosis (using the lowest T-score), 41 cases were identified as having osteoporosis. In 16 cases (15 %), osteoporosis would be misdiagnosed if only the OA side was evaluated (sensitivity: 61 %). Conversely, 5 cases (5 %) would be misdiagnosed if only the healthy side was assessed with a sensitivity of 88 % (Fig. 3c).

Table 2
Comparison of the BMD between the osteoarthritic and the healthy sides.

Parameters	OA side (g/cm^2)	Healthy side (g/cm^2)	Diff. (g/cm^2)	Abs. diff. (g/cm^2)	% diff. (%)	abs. % diff. (%)	p-Value
CT-aBMD	0.709 ± 0.127	0.755 ± 0.132	0.054 (0.004–0.091)	0.059 (0.029–0.095)	6.9 (0.6–11.8)	8.0 (4.1–12.2)	<0.001
CT-aBMD(neck)	0.729 ± 0.119	0.630 ± 0.116	−0.093 (−0.150 to −0.036)	0.095 (0.045–0.150)	−14.5 (−26.0 to −6.0)	14.8 (7.0–26.0)	<0.001
CT-aBMD(dist.)	0.866 ± 0.154	0.957 ± 0.152	0.093 (0.027–0.148)	0.095 (0.050–0.148)	9.4 (2.8–14.8)	10.2 (5.6–14.9)	<0.001

Data are expressed as means ± standard deviations or medians (interquartile range). p-values calculated for the BMDs between the OA and healthy sides. BMD, bone mineral density; abs., absolute; OA, osteoarthritis; diff., difference.

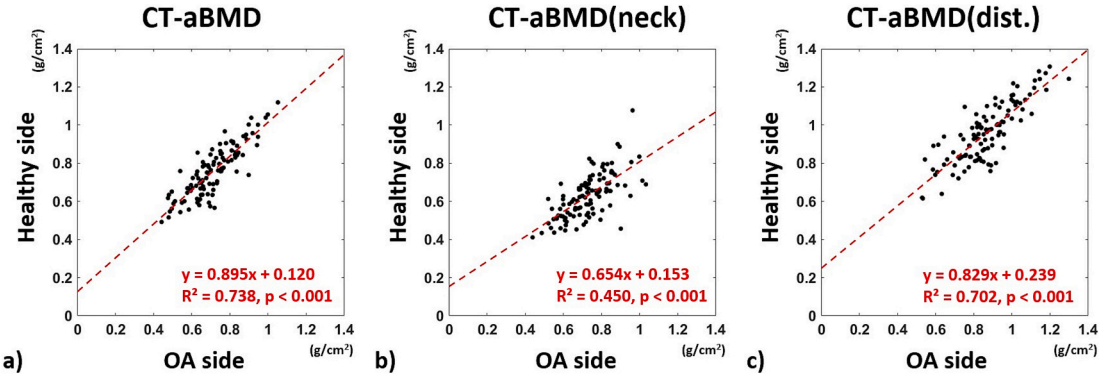

Fig. 2. The correlation of BMD between the OA side and the healthy side for the total (a), neck (b), and distal regions (c). For each regression analysis, the regression line of each parameter is indicated by a red dotted line. The regression equation, R^2 values, and *p*-values are presented in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Bivariate analysis for factors related to the %decrease in CT-aBMD of the OA side.

Parameters	Value	p-Value
Age	r_s = −0.322	<0.001
Weight	r_s = 0.059	0.54
Crowe classification	Type 1: 6.7 % (0.5–11.4) Type 2: 12.6 % (2.6–18.2)	0.12
Bombelli classification	Hypertrophic*: −5.1 % (−12.9–10.4) Normotrophic*: 7.5 % (1.5–12.0) Atrophic: 6.8 % (−1.3–11.0)	0.02
Knee OA	None: 6.8 % (0.8–11.8) Healthy side: 10.5 % (−3.5–20.1) OA side: −10.4 % (−27.1–16.0)	0.44
JOA hip score sum diff.	r_s = 0.175	0.07
Gluteus %atrophy	r_s = 0.333	<0.001
Gluteus HU diff.	r_s = 0.143	0.14

OA, osteoarthritis; JOA, Japanese Orthopaedic Association; diff., difference; HU, Hounsfield Units.
* Significant between-group difference.

Table 4
Bivariate analysis for factors related to the %decrease in CT-aBMD(neck) of the OA side.

Parameters	Value	p-Value
Age	r_s = −0.278	0.004
Weight	r_s = 0.064	0.51
Crowe classification	Type 1: −14.3 % (−25.2 to −5.5) Type 2: −32.4 % (−44.7 to −4.7)	0.17
Bombelli classification	Hypertrophic*,#: −42.0 % (−48.5 to −28.2) Normotrophic*: −14.1 % (−22.3 to −3.7) Atrophic#: −11.4 % (−14.6 to −5.4)	<0.001
Knee OA	None: −14.6 % (−25.8 to −5.0) Healthy side: −10.5 % (−13.6 to −5.5) OA side: −28.8 % (−97.2 to −7.1)	0.34
JOA hip score sum diff.	r_s = 0.029	0.76
Gluteus %atrophy	r_s = −0.015	0.88
Gluteus HU diff.	r_s = −0.043	0.66

OA, osteoarthritis; JOA, Japanese Orthopaedic Association; diff., difference; HU, Hounsfield Units.
* Significant between-group difference.
# Significant between-group difference.

4. Discussion

This study utilized quantitative CT images to evaluate the differences in BMD between the two sides in patients with unilateral hip OA. We observed a median absolute %BMD difference of 8.0 % for the total region and 14.8 % for the neck region, with over 70 % of cases surpassing the LSC defined in ISCD's official guidelines. When diagnosing osteoporosis based on the lowest T-score in both regions, assessing the healthy side demonstrated greater sensitivity. Therefore, although bilateral measurements are preferred, we suggest performing a DXA scan on the healthy side if only one side can be scanned.

4.1. Comparison with previous studies reporting side-to-side BMD differences

Previous studies utilizing control cases have assessed BMD on both sides, revealing robust correlations of 0.94–0.96 and 0.91–0.94 for the total and neck regions, respectively [26–29]. This study found lower correlations between the OA and healthy sides, with values of 0.859 and 0.671 for the total and neck regions, respectively. Additionally, upon comparison, the median difference (total: 0.054 g/cm^2 and neck: 0.093 g/cm^2) was larger than that reported by Chen et al. (total: 0.001 g/cm^2, neck: 0.003 g/cm^2) in an extensive survey of 17,169 cases [29]. Although not directly comparable to those of previous studies, these findings highlight the importance of the appropriate side for measurement during DXA in patients with unilateral OA. Notably, the side-to-side difference surpassed the LSC in 72 % of cases for the total region and 76 % for the neck region, a higher percentage than reported by Ikegami et al. [26] using control subjects (total region: 70 %, neck region: 58 %) even the LSCs were set lower in their study (total region: 1.8 %, neck region: 3.2 %).

Compared with studies analyzing side-to-side BMD differences in control subjects, information in unilateral OA patients has been limited.

Table 5
Multivariate analysis for factors related to the %decrease in CT-aBMD of the OA side.

Parameters	β	SE	Lower limit	Upper limit	p-Value
Intercept	1.02	8.52	−15.82	17.87	0.90
Age	−0.17	0.07	−0.32	−0.03	0.02
Weight	0.01	0.08	−0.15	0.18	0.87
Crowe classification (type 2)	5.44	3.54	−1.55	12.44	0.13
Bombelli classification (atrophic)	5.30	1.55	2.23	8.37	0.001
Bombelli classification (hypertrophic)	−8.79	1.73	−12.21	−5.37	<0.001
Knee OA (hip affected side)	−6.19	3.29	−12.68	0.31	0.06
Knee OA (hip healthy side)	4.69	2.98	−1.20	10.58	0.12
JOA hip score sum diff.	0.10	0.07	−0.03	0.24	0.13
Gluteus volume %atrophy	0.41	0.11	0.19	0.62	<0.001
Gluteus HU diff.	0.07	0.07	−0.07	0.20	0.33

OA, osteoarthritis; JOA, Japanese Orthopaedic Association; diff., difference; HU, Hounsfield Units.

Table 6
Multivariate analysis for factors related to the %decrease in CT-aBMD(neck) of the OA side.

Parameters	β	SE	Lower limit	Upper limit	p-value
Intercept	−16.36	15.07	−46.17	13.44	0.28
Age	−0.30	0.13	−0.56	−0.05	0.02
Weight	0.01	0.15	−0.29	0.30	0.97
Crowe classification (type 2)	−5.98	6.26	−18.35	6.40	0.34
Bombelli classification (atrophic)	12.55	2.74	7.12	17.98	<0.001
Bombelli classification (hypertrophic)	−19.05	3.06	−25.10	−13.00	<0.001
Knee OA (hip affected side)	−11.07	5.81	−22.57	0.42	0.06
Knee OA (hip healthy side)	7.28	5.27	−3.13	17.70	0.17
JOA hip score sum diff.	0.13	0.12	−0.10	0.37	0.27
Gluteus volume % atrophy	0.35	0.19	−0.03	0.73	0.07
Gluteus HU diff.	0.10	0.12	−0.13	0.34	0.39

SE, standard error; OA, osteoarthritis; JOA, Japanese Orthopaedic Association; diff., difference; HU, Hounsfield Units.

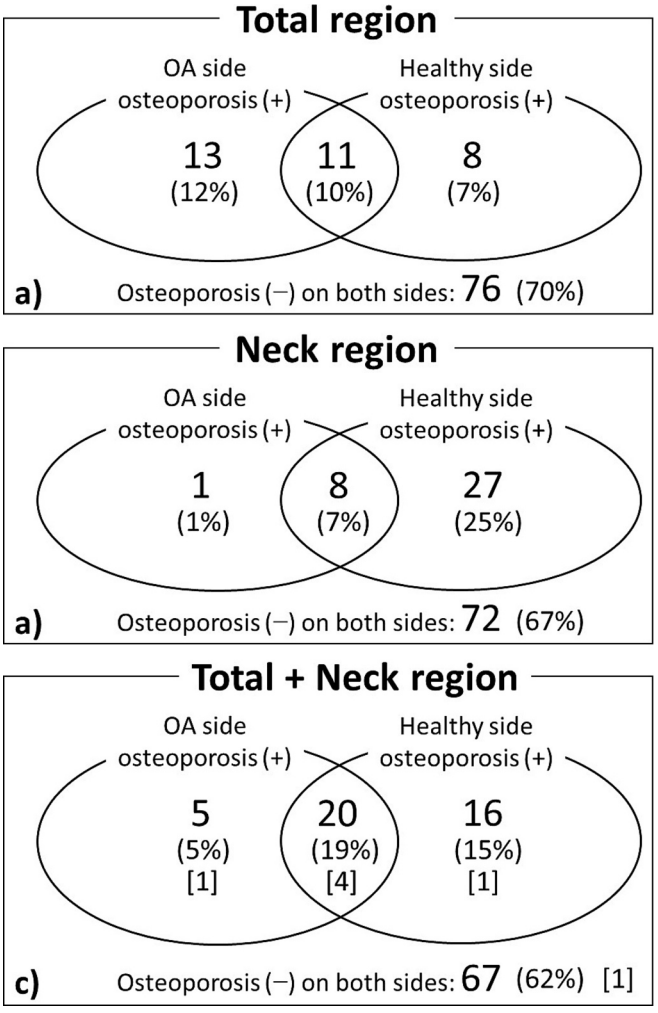

Fig. 3. Venn diagram of the OA and healthy sides to detect osteoporosis for the total (a), neck (b), and both regions (c). Numbers and percentages indicate cases and percentages included in each category. In section (a), 13 (12 %) cases exhibited osteoporosis only on the OA side, 8 (7 %) cases only on the healthy side, and 11 (10 %) cases on both sides; additionally, 76 cases (70 %) displayed no osteoporosis on either side. For (c), the numbers in the brackets indicate the number of cases diagnosed with osteoporosis based on the DXA measurements of the lumbar.

Glowacki et al. [8] analyzed 34 cases with unilateral hip OA. They found notable disparities in the neck region (greater for the OA hip) and no significant differences in the total region. They recommended measuring the healthy side or utilizing the total region of the OA side, which aligns with our study. However, Glowacki et al. [8] only analyzed one case that could be diagnosed as osteoporosis, and the results may not be directly compared. Kobayashi et al. [9] analyzed regional BMD differences between the OA and the healthy sides using DXA in 69 cases. The study observed a 28 % increase in BMD in the neck region and a 10 % decrease in the distal region, presenting results that, while more significant, align closely with our findings. Nonetheless, our research stands apart from earlier reports, introducing a novel perspective on how BMD differences affect osteoporosis diagnosis.

4.2. Factor analysis

In examining the factors influencing side-to-side BMD differences, age, Bombelli classification, and the percentage of gluteus volume atrophy were significant for the total region (Table 5). In the neck region, age and Bombelli classification emerged as significant factors (Table 6). These findings suggest that in patients with OA, BMD in the affected hips is lower compared to the healthy side for younger individuals and those classified as atrophic, as per Bombelli. Conversely, the hypertrophic classification of Bombelli is associated with higher BMD in the OA hips. We assume that osteophytes and sclerosis extending to the femoral neck, predominantly found in the hypertrophic type, affected the BMD, especially in the neck region, as reported in previous reports [30].

The amount of gluteus muscle atrophy was also a significant factor for BMD divergence for the total region. Studies have shown the contribution of the gluteal muscles to hip stabilization and hip abduction [31]. Still, this finding is likely due to the disuse of the OA hip, often evaluated through the atrophy measurements of the gluteal muscles [32]. The BMD decrease of 9.4 % in the distal region supports this finding. Conversely, gluteal atrophy was not a significant contributor to the neck region. Although the precise causation is uncertain, it is likely that the greater impact of osteophytes and sclerosis on neck region BMD obscured this effect.

This study examined various patient demographics and radiological and functional factors; however, other elements could influence the side-to-side differences. Notably, data regarding the dominant foot, which was not included in this analysis, has been shown to impact the side-to-side BMD variations [33]. Nonetheless, the impact is minimal or

nonexistent, given that the reported difference is <2 %.

4.3. Effect of side-to-side BMD differences in the diagnosis of osteoporosis and the application of the results for clinical intervention

Only a few cases (7) were diagnosed with osteoporosis based solely on lumbar DXA (Fig. 3c). This underscores the necessity of assessing BMD at the hip for patients suffering from unilateral hip OA, consistent with earlier findings [34]. When analyzing the side-to-side differences in the total and neck regions, over 70 % of the cases showed differences that exceeded the LSC, emphasizing the need for BMD measurements of both hips. Conversely, diagnosing osteoporosis using measurements from both regions yielded a high sensitivity on the healthy side (88 %, Fig. 3c). Therefore, we suggest measuring the healthy side when only one side can be assessed for an effective osteoporosis diagnosis. It is essential to recognize that evaluating the BMD in the total region of the OA side is critical for diagnosis, as it is typically lower than that on the healthy side, especially in young individuals and those with atrophic OA type. Additionally, assessing the BMD on the OA side is vital while contemplating the primary implant fixation in cementless stems [6] and preventing periprosthetic femoral fractures [35,36]. Moreover, post-operative anti-osteoporotic medications can mitigate BMD loss around the stem [37,38]. Our study aims to improve postoperative osteoporosis treatment by accurately identifying this condition, potentially resulting in better long-term surgical outcomes. These evaluations could be prompted by assessing the total region of the OA side because the BMD in the neck region of the OA side typically exceeds that of the healthy side.

4.4. Limitations

This study has certain limitations. Primarily, it only includes women who had hip arthroplasty for unilateral hip OA, as hip OA and osteoporosis predominantly affect women in Japan [39]. While results may vary for men, we believe that the absence of men's data does not diminish the significant findings of this study. Additionally, our analysis relied on BMD measurements derived from quantitative CT images, which may differ from BMD measurements taken in clinical settings using DXA. Nonetheless, the ISCD guidelines endorse using CT images for BMD quantification [40], and using CT images allows us to detect morphological differences in the femur that underlie unilateral hip OA cases [10].

5. Conclusions

In patients with unilateral hip OA, BMD measurements from both hips showed that the OA-affected side had a 6.9 % lower BMD overall while exhibiting a 14.5 % higher BMD in the neck region. Factor analysis revealed that younger age and the atrophic type, as defined by Bombelli, correlated with lower BMD on the OA side in both the total and neck areas. Moreover, significant contributions to the decreased BMD on the OA side in the total region were linked to the extent of gluteal atrophy. The unaffected side displayed a higher sensitivity (88 %) for diagnosing osteoporosis using measurements from both hips. These findings suggest that the healthy side may effectively aid in diagnosing osteoporosis. However, it is essential to exercise caution for younger patients with atrophic OA, as their OA side's BMD is likely lower than that of the healthy side, highlighting the need for bilateral BMD assessments.

CRediT authorship contribution statement

Keisuke Uemura: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sotaro Kono:** Formal analysis, Data curation. **Kazuma Takashima:** Writing – review & editing. **Kazunori Tamura:** Resources. **Ryo Higuchi:** Writing – review & editing. **Hirokazu Mae:** Writing – review & editing. **Nobuo Nakamura:** Resources. **Yoshito Otake:** Writing – review & editing, Supervision. **Yoshinobu Sato:** Supervision. **Nobuhiko Sugano:** Resources. **Seiji Okada:** Supervision. **Hidetoshi Hamada:** Writing – review & editing, Supervision.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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