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Bone mineral density differs by proximal femoral fracture location but not by fracture morphology

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Abstract

Whether the morphology of proximal femoral fractures reflects skeletal fragility remains unclear. Using a prospective multicenter registry of consecutive patients who underwent surgery for proximal femoral fracture at six Japanese hospitals between 2023 and 2026, we compared bone mineral density (BMD) and bone turnover markers across fracture locations and morphological subtypes. Femoral neck fractures were classified by the Garden classification and trochanteric fractures by the AO/OTA classification, with 31A2 fractures subdivided by fragment number on computed tomography. Of 1,724 patients analyzed (866 femoral neck and 858 trochanteric fractures), those with trochanteric fractures had lower BMD at the total hip (adjusted difference − 0.053 g/cm², 95% confidence interval − 0.067 to − 0.040), femoral neck, and lumbar spine (all P < 0.001). Within fracture types, total hip BMD did not differ between displaced and non-displaced femoral neck fractures (− 0.007, − 0.032 to 0.017), and more fragments were not associated with lower BMD in trochanteric fractures. Procollagen type I N-terminal propeptide was higher in trochanteric fractures, whereas tartrate-resistant acid phosphatase 5b and 25-hydroxyvitamin D did not differ. BMD was associated with fracture location but not with fracture morphology, suggesting that fracture type does not necessarily reflect the severity of osteoporosis.

Introduction

Proximal femoral fractures are osteoporotic fractures that substantially compromise survival and functional independence in older adults [1,2], and their global burden continues to increase with population aging. In Japan, one of the most rapidly aging countries worldwide, more than 120,000 cases were registered in the 2023 nationwide survey [3,4]. Treatment strategies depend largely on fracture location and morphology. For femoral neck fractures, displacement is a major determinant of the choice between internal fixation and arthroplasty [5,6]. For trochanteric fractures, fracture stability according to the AO/OTA classification and the number of fragments influence implant selection and postoperative outcomes [7,8]. More recently, classifications based on three-dimensional computed tomography (CT) have been proposed to better characterize fracture fragments that are difficult to assess on plain radiographs [9,10].

The relationship between fracture location and skeletal fragility has long been discussed. Patients with trochanteric fractures have repeatedly been reported to be older and to have lower bone mineral density (BMD) than those with femoral neck fractures [11–13]. Nationwide surveys in Japan have also shown that the relative frequencies of these two fracture types reverse at approximately 75 years of age [4,14]. Furthermore, the ratio of femoral neck to trochanteric fractures differs substantially between Nordic countries and Japan, suggesting that skeletal geometry characteristic of Asian populations may contribute to differences in fracture location [4,15,16]. Despite their large sample sizes, nationwide surveys classify fractures only as femoral neck or trochanteric fractures and do not collect BMD or bone turnover marker data [4]. Conversely, clinical studies examining the relationship between detailed fracture patterns and BMD have yielded inconsistent findings. One study reported lower intertrochanteric BMD in patients

with unstable rather than stable trochanteric fractures [17], whereas a quantitative CT study found higher BMD in those with unstable fractures [18]. Studies of femoral neck fractures have generally found no association between BMD and displacement [17,19,20]. Most of these studies were conducted at single centers and included tens to hundreds of patients, while few also examined markers of bone turnover. Few studies have simultaneously evaluated detailed fracture patterns and skeletal parameters in large cohorts, addressing aspects not captured by nationwide surveys.

Characterizing skeletal status across fracture types may help clarify the extent to which differences in fracture patterns reflect the severity of osteoporosis. We hypothesized that BMD would be associated with fracture location but not with the severity of fracture morphology. Using a multicenter registry of consecutive patients, this study aimed to characterize the distribution of proximal femoral fracture locations and morphologies and to describe BMD and bone turnover marker profiles across fracture types. We also examined the association between fracture morphology and BMD, for which previous studies have yielded conflicting findings.

Methods

Study design and participants

This study analyzed data from a prospective multicenter registry involving six hospitals in Hokkaido, Japan. Participating institutions were general hospitals treating at least 80 proximal femoral fractures annually. A total of 1,823 consecutive patients who underwent surgery for proximal femoral fractures at the participating institutions between April 2023 and March 2026 were registered.

The exclusion criteria were age < 50 years (n = 24), pathological fractures (n = 5), high-energy trauma (traffic accidents, n = 5; falls from height, n = 14), subchondral insufficiency fractures of the femoral head (n = 4), atypical femoral fractures (n = 2), periprosthetic fractures (n = 4), subtrochanteric fractures (n = 36), and missing data on key variables (n = 5). Subtrochanteric fractures were excluded because their injury mechanisms and fracture morphology differ from those of the other fracture types and because the number of cases was limited. The final analysis included 1,724 patients: 866 with femoral neck fractures and 858 with trochanteric fractures. his study was approved by the Institutional Review Board of Hokkaido University Hospital (No. 023–0187) and by the ethics committees of all participating institutions. All methods were performed in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects in Japan. Written informed consent was obtained from patients or their legal guardians, or an opt-out approach was used, in accordance with the policy of each participating institution. Where the opt-out approach was used, the requirement for written informed consent was waived by the respective ethics committee, and information about the study was made publicly available so that patients or their families could decline participation.

Fracture classification

Fractures were classified as femoral neck or trochanteric fractures. Femoral neck fractures were classified according to the Garden classification as nondisplaced (stages I–II) or displaced (stages III–IV) [21]. Trochanteric fractures were classified as AO/OTA types 31A1, 31A2, or 31A3. Type 31A2 fractures were further subdivided into three-part and four-or-more-part groups according to the number of fragments identified on CT [22].

All patients underwent CT after injury, and fracture classification was based on both plain radiographs and CT images. Two hip surgeons independently classified the fractures. Disagreements were adjudicated by a third specialist to determine the final classification. In a randomly selected sample of 210 patients, interobserver agreement, assessed using Cohen's κ, was 0.70 (95% confidence interval [CI], 0.62–0.78) for nondisplaced femoral neck fractures, 0.79 (0.71–0.87) for displaced femoral neck fractures, 0.89 (0.80–0.98) for 31A1 fractures, 0.84 (0.75–0.93) for 31A2 three-part fractures, 0.87 (0.78–0.96) for 31A2 four-or-more-part fractures, and 0.83 (0.74–0.92) for 31A3 fractures, indicating good agreement across all categories.

Bone mineral density and bone turnover marker

BMD was measured using the same model of dual-energy X-ray absorptiometry (DXA) scanner (Hologic) at all participating institutions. Measurements were obtained at the lumbar spine, total hip, and femoral neck, with hip measurements performed on the contralateral, unfractured side. DXA was performed immediately after surgery. T-scores were calculated using Japanese young-adult reference values. Tartrate-resistant acid phosphatase 5b (TRACP5b), a marker of bone resorption; procollagen type I N-terminal propeptide (P1NP), a marker of bone formation; and serum 25-hydroxyvitamin D (25OHD) were measured. Blood samples were collected on admission following injury. TRACP5b was measured using an enzyme immunoassay (EIA), whereas P1NP and 25OHD were measured using electrochemiluminescence immunoassays (ECLIA).

Covariates

Age, sex, height, weight, preinjury activities of daily living (ADL), comorbidities, medication use, and history of fragility fractures were recorded in the registry. Sex was defined as biological sex documented in the medical records. Body mass index (BMI) was calculated from height and weight. Preinjury ADL was classified into three categories: independent ambulation (outdoors or indoors), ambulation with an assistive device (cane or walker), and wheelchair use or bedridden status. Recorded comorbidities included chronic kidney disease, diabetes mellitus, thyroid disease, and malignancy. Corticosteroid and proton pump inhibitor use was also recorded, as was preoperative osteoporosis treatment.

Statistical analysis

Continuous variables are presented as means ± standard deviations, and categorical variables as counts and percentages. The proportions of fracture types are reported with 95% CIs calculated using the Wilson method. Patient characteristics were compared between femoral neck and trochanteric fractures using the Mann–Whitney U test for continuous variables and the chi-square test for categorical variables. Differences in BMD and bone turnover markers across fracture types were assessed using multivariable linear regression, adjusting for age, sex, BMI, preoperative osteoporosis treatment, and institution. Bone turnover markers were natural log-transformed to account for skewed distributions, and between-group differences were expressed as geometric mean ratios. Adjusted means were calculated as predicted values with covariates held at their sample means. To assess the association between fragment number and BMD in trochanteric fractures, 31A1, 31A2 three-part, and 31A2 four-or-more-part fractures were entered as an ordinal variable, and a test for trend was performed.

The primary outcome was the difference in total hip BMD between femoral neck and trochanteric fractures. All other analyses were considered exploratory. Sensitivity analyses included a model additionally adjusted for comorbidities (chronic kidney disease, diabetes mellitus, thyroid disease, and malignancy), corticosteroid and proton pump inhibitor use, history of fragility fractures, and preinjury ADL, as well as a model restricted to women. Missing values were not imputed, and each analysis included patients with available data for the variables required for that analysis. Statistical significance was set at a two-sided p-value < 0.05. All analyses were performed using JMP version 19.0 (SAS Institute, Cary, NC, USA).

Results

Patient characteristics

Of the 1,823 consecutive cases registered, 99 were excluded, leaving 1,724 patients (866 femoral neck fractures and 858 trochanteric fractures) for analysis (Fig. 1). The mean age of the whole cohort was 83.5 ± 9.8 years, and 53.2% of patients were aged 85 years or older. Women accounted for 78.2% of the cohort, and the mean body mass index was 21.0 ± 3.7 kg/m². Patients with trochanteric fractures were older than those with femoral neck fractures (86.3 ± 8.5 vs 80.6 ± 10.1 years, P < 0.001), were less often ambulatory without assistance before injury (55.9% vs 71.9%, P < 0.001), and were more likely to have received osteoporosis treatment before the fracture (20.5% vs 14.1%, P < 0.001). A previous fragility fracture was also more common in patients with trochanteric fractures (29.1% vs 23.3%, P = 0.007). Comorbidities and medication use were comparable between the two groups, except for proton pump inhibitor use (27.7% vs 21.2%, P = 0.002) (Table 1).

Table 1
Baseline characteristics of patients with femoral neck and trochanteric fractures.

Variable	All (n = 1724)	Femoral neck fx. (n = 866)	Trochanteric fx. (n = 858)	P value
Age, years	83.5 (9.8)	80.6 (10.1)	86.3 (8.5)	< 0.001
Female, %	78.2	75.6	80.9	0.010
Body mass index, kg/m^2	21.0 (3.7)	20.8 (3.5)	21.2 (3.8)	0.063
Pre-injury ambulatory status				< 0.001
Independent, %	64.0	71.9	55.9	
Walking aid, %	28.3	21.4	35.3	
Wheelchair or bedridden, %	7.7	6.7	8.7	
Prior osteoporosis treatment, %	17.3	14.1	20.5	< 0.001
Previous fragility fracture, %	26.2	23.3	29.1	0.007
Chronic kidney disease, %	10.7	12.0	9.4	0.100
Diabetes mellitus, %	19.2	18.8	19.6	0.735
Thyroid disease, %	3.5	3.1	4.0	0.413
Malignancy, %	14.0	14.9	13.2	0.336
Glucocorticoid use, %	3.2	3.6	2.8	0.431
Proton pump inhibitor use, %	24.5	21.2	27.7	0.002
Hypnotic use, %	16.9	16.6	17.1	0.829
Antidepressant use, %	6.0	6.5	5.5	0.445
Antithrombotic use, %	26.1	24.8	27.4	0.248

Values are presented as mean (standard deviation) or percentage. P values compare femoral neck and trochanteric fractures using the Mann–Whitney U test for continuous variables and the chi-square test for categorical variables; the P value for pre-injury ambulatory status refers to the overall comparison across the three categories. Body mass index was calculated from height and body weight. fx., fracture.

Distribution of fracture types and morphological subtypes

There were 866 femoral neck fractures (50.2%, 95% CI 47.9–52.6) and 858 trochanteric fractures (49.8%, 47.4–52.1), giving a femoral neck-to-trochanteric ratio of 1.01. Among femoral neck fractures, 174 were

non-displaced (20.1% within fracture type, 95% CI 17.6–22.9) and 692 were displaced (79.9%, 77.1–82.4). Among trochanteric fractures, 269 were classified as 31A1 (31.4%, 28.3–34.5) and 550 as 31A2 (64.1%), of which 394 were 3-part (45.9%, 42.6–49.3) and 156 were ≥ 4-part (18.2%, 15.7–20.9); 39 fractures were classified as 31A3 (4.5%, 3.3–6.2) (Table 2).

Table 2
Distribution of fracture types and morphological subtypes.

Fracture type	n	% of all fractures (95%CI)	% within fracture type (95%CI)
Femoral neck fracture	866	50.2 (47.9–52.6)	
Non-displaced	174	10.1 (8.8–11.6)	20.1 (17.6–22.9)
Displaced	692	40.1 (37.8–42.5)	79.9 (77.1–82.4)
Trochanteric fracture	858	49.8 (47.4–52.1)	
31A1	269	15.6 (14.0-17.4)	31.4 (28.3–34.5)
31A2, 3-part	394	22.9 (20.9–24.9)	45.9 (42.6–49.3)
31A2, ≧4-part	156	9.0 (7.8–10.5)	18.2 (15.7–20.9)
31A3	39	2.3 (1.7–3.1)	4.5 (3.3–6.2)

Percentages of all fractures are based on the 1,724 patients analyzed; percentages within fracture type are based on 866 femoral neck fractures and 858 trochanteric fractures. Femoral neck fractures were classified according to the Garden classification and trochanteric fractures according to the AO/OTA classification, with 31A2 fractures subdivided by the number of fragments on computed tomography. Confidence intervals were calculated using the Wilson method. CI, confidence interval.

Bone mineral density

Adjusted means of bone mineral density are shown in Table 3. Compared with femoral neck fractures, trochanteric fractures were associated with lower bone mineral density at the total hip (adjusted difference − 0.053 g/cm², 95% CI − 0.067 to − 0.040, P < 0.001), the femoral neck (− 0.033, − 0.045 to − 0.022, P < 0.001), and the lumbar spine (− 0.061, − 0.080 to − 0.043, P < 0.001) (Table 4). In contrast, no differences in bone mineral density were observed within each fracture type. Among femoral neck fractures, total hip bone mineral density did not differ between displaced and non-displaced fractures (− 0.007, − 0.032 to + 0.017, P = 0.556), and no significant differences were found at the femoral neck (− 0.018, − 0.039 to + 0.002, P = 0.079) or the lumbar spine (− 0.029, − 0.060 to + 0.001, P = 0.062).

Table 3
Adjusted means of bone mineral density and bone turnover markers according to fracture type and morphology

Variable	Non-displaced	Displaced	31A1	31A2 3part	31A2 ≧ 4part	31A3
Total hip BMD g/cm^2	0.634 (0.604–0.663)	0.624 (0.602–0.646)	0.557 (0.531–0.584)	0.572 (0.548–0.596)	0.587 (0.558–0.617)	0.594 (0.548–0.640)
Femoral neck BMD g/cm^2	0.565 (0.541–0.589)	0.545 (0.527–0.563)	0.501 (0.480–0.523)	0.516 (0.496–0.536)	0.530 (0.505–0.555)	0.541 (0.501–0.581)
Lumbar spine BMD g/cm^2	0.922 (0.882–0.961)	0.892 (0.862–0.922)	0.834 (0.798–0.870)	0.831 (0.799–0.864)	0.850 (0.810–0.890)	0.830 (0.766–0.895)
TRACP5b, mU/dL	426 (375–483)	366 (332–403)	404 (360–453)	410 (369–455)	344 (303–391)	408 (335–496)
P1NP, μg/L	76 (63–92)	81 (70–94)	91 (77–108)	91 (78–107)	97 (80–117)	121 (90–163)
25(OH)D, ng/mL	11.4 (9.0–14.5)	9.6 (8.2–11.2)	10.0 (8.3–12.1)	9.8 (8.2–11.6)	11.1 (8.9–13.9)	13.3 (8.6–20.3)

Values are adjusted means with 95% confidence intervals, estimated from multivariable linear regression models adjusted for age, sex, body mass index, prior osteoporosis treatment, and institution. Bone turnover markers were natural log-transformed and are presented as geometric means. BMD, bone mineral density; TRACP5b, tartrate-resistant acid phosphatase 5b; P1NP, procollagen type I N-terminal propeptide; 25(OH)D, 25-hydroxyvitamin D.

Table 4
Adjusted differences in bone mineral density and bone turnover markers between fracture types and morphological subtypes.

Variable	Trochanteric vs femoral neck	Displaced vs non-displaced	31A1 vs 31A2 3part	31A1 vs 31A2 ≧ 4part	31A1 vs 31A3
Total hip BMD g/cm^2	-0.053* (-0.067 to -0.040)	-0.007 (-0.032 to 0.017)	0.016 (-0.007 to 0.038)	0.031 (0.003 to 0.059)	0.037 (-0.009 to 0.083)
Femoral neck BMD g/cm^2	-0.033* (-0.045 to -0.022)	-0.018 (-0.039 to 0.002)	0.014 (-0.004 to 0.032)	0.028 (0.005 to 0.051)	0.036 (-0.003 to 0.075)
Lumbar spine BMD g/cm^2	-0.061* (-0.080 to -0.043)	-0.029 (-0.060 to 0.001)	-0.003 (-0.035 to 0.028)	0.016 (-0.024 to 0.056)	-0.006 (-0.075 to 0.062)
TRACP5b, mU/dL	1.05 (0.99 to -1.12)	0.87* (0.79 to 0.96)	1.00 (0.91 to 1.11)	0.84* (0.75 to 0.95)	1.01 (0.82 to 1.24)
P1NP, μg/L	1.17* (1.07 to 1.28)	1.04 (0.89 to 1.22)	0.99 (0.86 to 1.15)	1.04 (0.87 to 1.25)	1.30 (0.97 to 1.75)
25(OH)D, ng/mL	1.04 (0.93 to -1.16)	0.84 (0.68 to 1.05)	0.99 (0.83 to 1.17)	1.13 (0.92 to 1.40)	1.50 (0.98 to 2.28)

Values are adjusted mean differences with 95% confidence intervals for bone mineral density, and geometric mean ratios with 95% confidence intervals for bone turnover markers, estimated from multivariable linear regression models adjusted for age, sex, body mass index, prior osteoporosis treatment, and institution. Bone turnover markers were natural log-transformed. Asterisks indicate P < 0.05. BMD, bone mineral density; TRACP5b, tartrate-resistant acid phosphatase 5b; P1NP, procollagen type I N-terminal propeptide; 25(OH)D, 25-hydroxyvitamin D.

Among trochanteric fractures, an increasing number of fragments was not associated with lower bone mineral density; rather, bone mineral density tended to be higher. Compared with 31A1 fractures, 31A2 fractures with ≥ 4 fragments showed higher bone mineral density at the total hip (+ 0.031, + 0.003 to + 0.059, P = 0.030) and at the femoral neck (+ 0.028, + 0.005 to + 0.051, P = 0.017). Trend analysis across 31A1, 31A2 3-part, and 31A2 ≥ 4-part fractures confirmed this pattern at the total hip (P for trend = 0.032) and the femoral neck (P = 0.018), whereas no such trend was observed at the lumbar spine (P for trend = 0.544).

Bone turnover markers

TRACP5b did not differ between femoral neck and trochanteric fractures (geometric mean ratio 1.05, 95% CI 0.99–1.12, P = 0.105), whereas P1NP was higher in trochanteric fractures (1.17, 1.07–1.28, P < 0.001). Serum 25(OH)D was low in both groups, at approximately 10 ng/mL, with no difference between fracture types (1.04, 0.93–1.16, P = 0.503). Within each fracture type, TRACP5b was lower in displaced than in non-displaced femoral neck fractures (0.87, 0.79–0.96, P = 0.006) and lower in 31A2 fractures with ≥ 4 fragments than in 31A1 fractures (0.84, 0.75–0.95, P = 0.006). No significant within-type differences were observed for P1NP or 25(OH)D (Table 4).

Sensitivity analyses

Results were essentially unchanged in models additionally adjusted for comorbidities, glucocorticoid and proton pump inhibitor use, previous fragility fracture, and pre-injury ambulatory status (adjusted difference in total hip bone mineral density between trochanteric and femoral neck fractures − 0.052, − 0.066 to − 0.038, P < 0.001; P for trend within trochanteric fractures = 0.032). In the analysis restricted to women, the lower total hip bone mineral density in trochanteric fractures (− 0.052, − 0.067 to − 0.037, P < 0.001) and the higher P1NP (1.16, 1.04–1.28, P = 0.005) were preserved. The trend toward higher bone mineral density with an increasing number of fragments within trochanteric fractures was more evident in this analysis (total hip P for trend = 0.009, femoral neck P = 0.008).

Discussion

The main finding of this study is that bone mineral density differed according to the site of fracture but showed little association with the morphology of the fracture within each site. Patients with trochanteric fractures had lower bone mineral density than those with femoral neck fractures at the total hip, the femoral neck, and the lumbar spine. In contrast, neither the presence of displacement in femoral neck fractures nor the number of fragments in trochanteric fractures was associated with lower bone mineral density. The confidence intervals for the within-type differences did not include the magnitude of the difference observed between fracture sites, suggesting that a difference of comparable size is unlikely to be present within a fracture type. Taken together, bone fragility may be related to where a hip fracture occurs, rather than to the morphology that the fracture takes.

The distribution of fracture types observed in this study was similar to that reported in nationwide data. In the 26-year nationwide survey conducted by the Japanese Orthopaedic Association, the femoral neck-to-trochanteric ratio in 2023 was 1.10, with femoral neck fractures accounting for 52.2% and trochanteric fractures for 47.5% of cases [4]. In our cohort of approximately 1,800 consecutive cases, the corresponding ratio was 1.01, and the mean age (83.5 vs 83.3 years) and the proportion of women (78.2% vs 76.0%) were comparable [4]. Although the nationwide survey was not restricted to surgically treated patients, the reported operative rate was 94.7% [4], making substantial selection bias in our surgical cohort unlikely. Femoral neck-to-trochanteric ratios of approximately 1.5 to 2.0 have been reported in Western countries [15,16], and the distribution in our cohort is consistent with that reported in Asian populations [4]. Our observation that patients with trochanteric fractures were older and had lower

bone mineral density than those with femoral neck fractures is also in line with previous reports [17,18,23,24].

No consensus has been reached regarding the association between bone mineral density and fracture morphology within each fracture type. Kanazawa et al. [17] reported, using dual-energy X-ray absorptiometry of the contralateral hip in 252 women, that intertrochanteric bone mineral density was lower in unstable than in stable trochanteric fractures, whereas Li et al. [18] reported the opposite using quantitative computed tomography; our findings were in the same direction as the latter. The inconsistency among previous studies may reflect differences in the measurement site, the classification systems used, and the populations studied, although our data cannot determine which of these factors is responsible. At least in the present cohort, no morphological difference accompanied by lower bone mineral density was observed, either for the Garden classification or for the AO/OTA classification. Factors determining fracture morphology may include local bone structure that is not captured by areal bone mineral density, such as the geometry of the proximal femur [25,26] and the cortical thickness of the intertrochanteric region [27], as well as mechanical conditions such as the direction of the fall and the magnitude of the impact [28,29]. Bone turnover markers likewise showed no consistent association with fracture site or morphology, which is not inconsistent with reports that their ability to predict fracture risk is limited [30]. The extent to which differences in fracture type reflect differences in the severity of osteoporosis therefore appears limited on the basis of the present findings.

This study has some limitations. First, it was a cross-sectional study restricted to patients who had sustained a fracture, and therefore does not establish a causal relationship between bone mineral density and fracture type. Second, bone mineral density was measured on the contralateral femur, assuming left–right symmetry, and did not directly assess the local bone mass or trabecular structure at the fracture site itself. Third, only surgically treated patients were included, and patients managed conservatively were not represented. Fourth, the cohort was drawn from six hospitals in a single region of Japan, and generalization requires caution. Fifth, analyses other than the primary outcome were exploratory and were not adjusted for multiple comparisons; in particular, the within-type findings for bone turnover markers require confirmation in an independent cohort.

In patients with low-energy proximal femoral fractures, bone mineral density was associated with the site of the fracture but not with the morphology of the fracture within each site. Patients with trochanteric fractures had lower bone mineral density than those with femoral neck fractures, whereas no difference in bone mineral density was observed according to the presence of displacement in femoral neck fractures or the number of fragments in trochanteric fractures. Bone turnover markers likewise showed no consistent association with fracture type. Differences in fracture type do not necessarily reflect differences in the severity of osteoporosis.

Statements and Declarations

Author Contributions

Conceptualization, T.S.; methodology, T.S. and H.I.; validation, H.I.; formal analysis, T.S., S.S., K.A., Y.O. and K.K.; investigation, T.O., Y.N., S.S., K.A., S.Y. (Shunichi Yokota) and H.H.; resources, Y.N., S.S. and S.Y. (Shu Yamazaki); data curation, T.O. and Y.N.; writing—original draft preparation, T.S.; writing—review and editing, T.S. and H.I.; visualization, H.I.; supervision, N.I.; project administration, T.S. All authors have read and agreed to the published version of the manuscript.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no conflict of interest.

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Ethics approval

This study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments and approved by the Hokkaido University Hospital Institutional Review Board (#0023-0187).

Informed consent

Written informed consent was obtained from patients or their legal guardians, or an opt-out approach was used with a waiver of written consent approved by the respective ethics committees.

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Figures

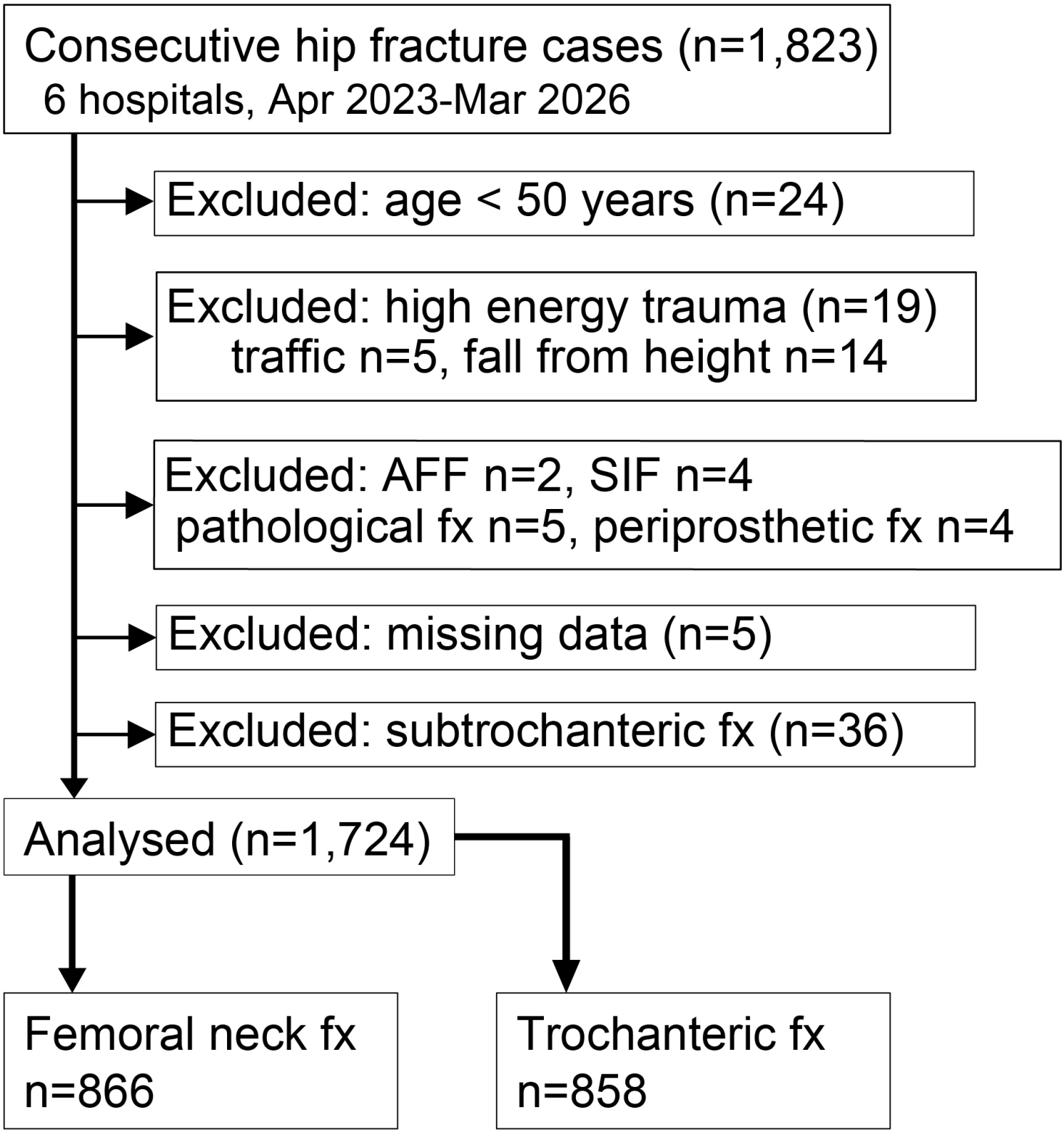


Figure 1

Flow diagram of patient selection.

AFF, atypical femoral fracture; SIF, subchondral insufficiency fracture; fx, fracture.