Original article

Inverse association between sarcopenia and displacement in the early phase of fragility fractures of the pelvis

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A R T I C L E   I N F O

A B S T R A C T

Objectives: Fragility fractures of the pelvis (FFP) commonly occur in the frail elderly. Displacement in the posterior pelvic ring is recognized as the key sign of instability. This study aims to elucidate the relationship between computer tomography (CT)-based frailty markers and displacement of the posterior pelvic ring within 7 days after injury.
Methods: This retrospective study included 49 patients (42 females, 7 males) with FFP (type I 10, type II 24, type III 12, type IV 3). On a CT slice at the level of the third lumbar vertebra, skeletal muscle area, skeletal muscle radiation attenuation, and skeletal muscle index (SMI) were calculated as sarcopenia markers. Osteopenia was measured with trabecular region of interest attenuation technique on the same CT slice.
Results: There was no difference in the demographics between non-displaced and displaced FFP. CT-based data showed that patients with FFP had osteopenia. However, no difference was found between non-displaced and displaced FFP. SMI was higher in FFP types III/IV than non-displaced FFP when CT-based data on sarcopenia were compared among all patients. Female patients with FFP demonstrated similar results. Logistic regression analysis using the demographics and CT-based markers on sarcopenia and osteopenia revealed that SMI was a potential determinant of displacement of the posterior pelvic ring fractures.
Conclusions: There was inverse association between sarcopenia and displacement of the posterior pelvic ring in the early phase of FFP. Relatively preserved muscle may develop displacement in the elderly with osteopenia.

1. Introduction

Fragility fractures of the pelvis (FFP) have received attention as a new entity of insufficiency fractures associated with osteoporosis [1]. A low-energy trauma such as a simple fall from a standing position often causes FFP in the elderly [2]. A comprehensive classification of FFP into 4 types has recently been proposed based on the findings on conventional radiographs and computed tomography (CT) scans [3]. Type I includes isolated anterior pelvic ring fractures. Type II shows non-displaced posterior pelvic ring lesions. Type III is characterized by a displaced unilateral posterior pelvic ring fracture in combination with an anterior pelvic ring lesion. Type IV demonstrates displaced bilateral posterior pelvic ring lesions. The typical fracture patterns of the posterior ring found in FFP may be explained by the specific locations with severe bone loss in the sacrum [4]. Any type of FFP can be caused by a low-energy trauma [1].

The classification system also offers a framework for the evaluation of the degree of instability. Because fracture displacement in the posterior pelvic ring is recognized as the leading sign of instability, types III and IV are unstable compared with type II [1]. Treatment is recommended for FFP according to the presence or absence of instability in the posterior pelvic ring. Conservative treatment is primarily provided for type II whereas operative stabilization is recommended for types III and IV with displaced posterior lesions [1]. Thus, the decision between nonsurgical and surgical treatment requires careful evaluation of displacement of the posterior pelvic ring fractures.

Fracture progression is observed in some patients with FFP. A

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transition from non-displaced to displaced FFP may develop with time [5,6]. Patients with FFP types III and IV have been reported to show longer time interval from injury to hospital presentation compared with those with FFP types I and II [5,6]. Thus, duration between injury and the first examination may contribute to displacement of the posterior pelvic ring fractures. Dislocation and large displacement of fracture fragments are rare in FFP, however, because the ligaments remain strong enough to contribute to pelvic stability [7]. The biomechanical parameters have been attempted to identify behind certain fracture types and the time-dependent development of pelvic disintegration [8–11]. Currently, the interaction between bone, ligament and muscle in FFP are still poorly understood. Furthermore, it is known that some patients suffer displaced FFP immediately after a low-energy trauma [12]. However, no literature has described specific factors that could cause displacement of the posterior ring in the early phase of FFP.

FFP commonly occur in frail individuals [1]. Frailty includes reduced mass and strength of muscle and bone [13]. Decreased skeletal muscle mass and function, or sarcopenia, is associated with increased risk of falls, rate of osteoporosis and fragility fracture, morbidity, and mortality [14–16]. Recently, CT has been used for measurements of frailty such as sarcopenia [17] and osteopenia [18]. This study aims to clarify association of CT-based frailty markers with displacement of the posterior pelvic ring in the early phase of FFP.

2. Methods

2.1. Study design and patients

After approval by the ethics committee of Kobe City Medical Center General Hospital (No. zn210101), this retrospective study was conducted using anonymized data with a general opt-out procedure.

By careful evaluation of injury mechanism and radiological data, FFP patients who were $\geq$ 65 years of age were identified from the electronic medical records between October 2011 and October 2019. There were 67 patients with FFP caused by a fall from a standing height. Of the 67 patients identified, 9 were excluded because they lacked information on their height (8 patients) or the date of injury (1 patient). Other 9 patients who presented at 7 days and more after injury were also excluded. The resultant 49 patients were enrolled in this study. The author (S.O.) of this study, an orthopedic trauma consultant specializing in pelvic and lower extremity trauma, classified all fractures using the classification system proposed by Rommens and Hofmann [3] (Fig. 1) on the basis of the findings on radiographs and CT taken at the first examination. As a result, 10 and 24 patients were classified as non-displaced FFP type I (Ia: 10) and type II (IIa: 2; IIb: 5; IIc: 17), respectively. In addition, 12 and 3 patients were classified as displaced FFP type III (IIIa: 11; IIIb: 1) and type IV (IVc: 3), respectively.

From epidemiologic studies, the majority of patients with FFP were females [19]. The cutoffs of diagnostic criteria for sarcopenia are different between sexes [20,21]. Therefore, this study analyzed the data of all patients and of female patients separately. Initial CT potentially failed to demonstrate any fracture lesion in the posterior pelvic ring, whereas magnetic resonance imaging (MRI) has been shown to detect the complete injury pattern including CT-silent bone edema [22]. Because no MRI study was performed for patients with FFP type I, this study used the data of type I in combination with type II as non-displaced FFP. Thus, FFP type II in this study means the combination of FFP types I and II.

2.2. CT analysis

CT was taken within 7 days after injury in this study. Durations between injury and CT examination were 0, 3, and 6 days in 12, 1, and 2 patients, respectively, of all the patients with displaced FFP. Durations between injury and CT examination were 0, 3, and 6 days in 11, 1, and 1 patient, respectively, of the female patients with displaced FFP. CT image analysis was performed using SYNAPSE VINCENT software version 5.0 (Fujifilm, Tokyo, Japan).

Sarcopenia was evaluated by axial CT scans with 5 mm slice thickness taken at the first examination as validated previously [23]. On a single axial slice at the level of the third lumbar vertebra (L3), a group of muscles including the bilateral paraspinal (erector spinae, quadratus lumborum), psoas, rectus abdominis, transversus abdominis, and internal and external oblique muscles were analyzed with the threshold set at −29 to 150 Hounsfield units (HU) (Fig. 2), which corresponds to the density of skeletal muscle tissue [24]. Lumbar skeletal muscle area (SMA) was computed by summing up the area of the selected muscle pixels. SMA has been demonstrated to correlate strongly with whole body muscle mass in healthy adults [25]. Skeletal muscle radiation attenuation (SMRA) was computed as the mean HU value of all pixels included in SMA [26]. SMRA indicates a measure for muscle density inversely related to muscle lipid content, which is associated with poor prognosis in oncologic and intensive care patients [24,25]. Skeletal muscle index (SMI) was computed as SMA divided by the patient's height squared (cm^2/m^2). SMI at the level of lumbar vertebra has recently been employed for sarcopenia assessments in relation to poor clinical outcomes in orthopedic traumatology [27,28]. Sarcopenia was defined as SMI of < 55.4 cm^2/m^2 for male patients and SMI of < 38.5 cm^2/m^2 for female patients [29].

Osteopenia was measured with trabecular region of interest (ROI) attenuation technique as described previously [30]. A single ROI was placed in the center of the L3 vertebral body as a circle 10 mm in diameter and the degree of osteopenia was evaluated by mean attenuation measurements in HU on a standard PACS workstation. ROI attenuation measurements of the lumbar spine are effective for bone mineral density screening with high sensitivity for osteoporosis as defined by T-score of dual-energy X-ray absorptiometry [30]. Osteopenia was defined as < 120 HU [31].

2.3. Statistical analysis

After Shapiro-Wilk test of normality, data were compared between the 2 groups by t test and Mann-Whitney U test for parametric and nonparametric tests, respectively. Cohen's d was calculated for the comparison between the 2 means. Multiple logistic regression analysis was performed to determine significant variables for displacement of the posterior pelvic ring in FFP. Statistical analyses were conducted in SPSS for Windows, Version 25 (IBM Corp.; Armonk, NY, USA). The level of significance was set at P < 0.05.

3. Results

When baseline demographic characteristics were compared between patients with non-displaced (type II) and displaced (types III/IV) FFP, no difference was found in age, body mass index, or height (Table 1). In comparison of CT-based data on osteopenia, there was no difference in ROI attenuation measurements in L3 between FFP type II and types III/IV (Table 1). SMI was significantly lower in all patients with FFP type II compared with those with FFP types III/IV (P = 0.034, Cohen's d = 0.91), whereas SMA or SMRA demonstrated no difference between FFP type II and types III/IV (Table 1). When CT-based data on osteopenia and sarcopenia was
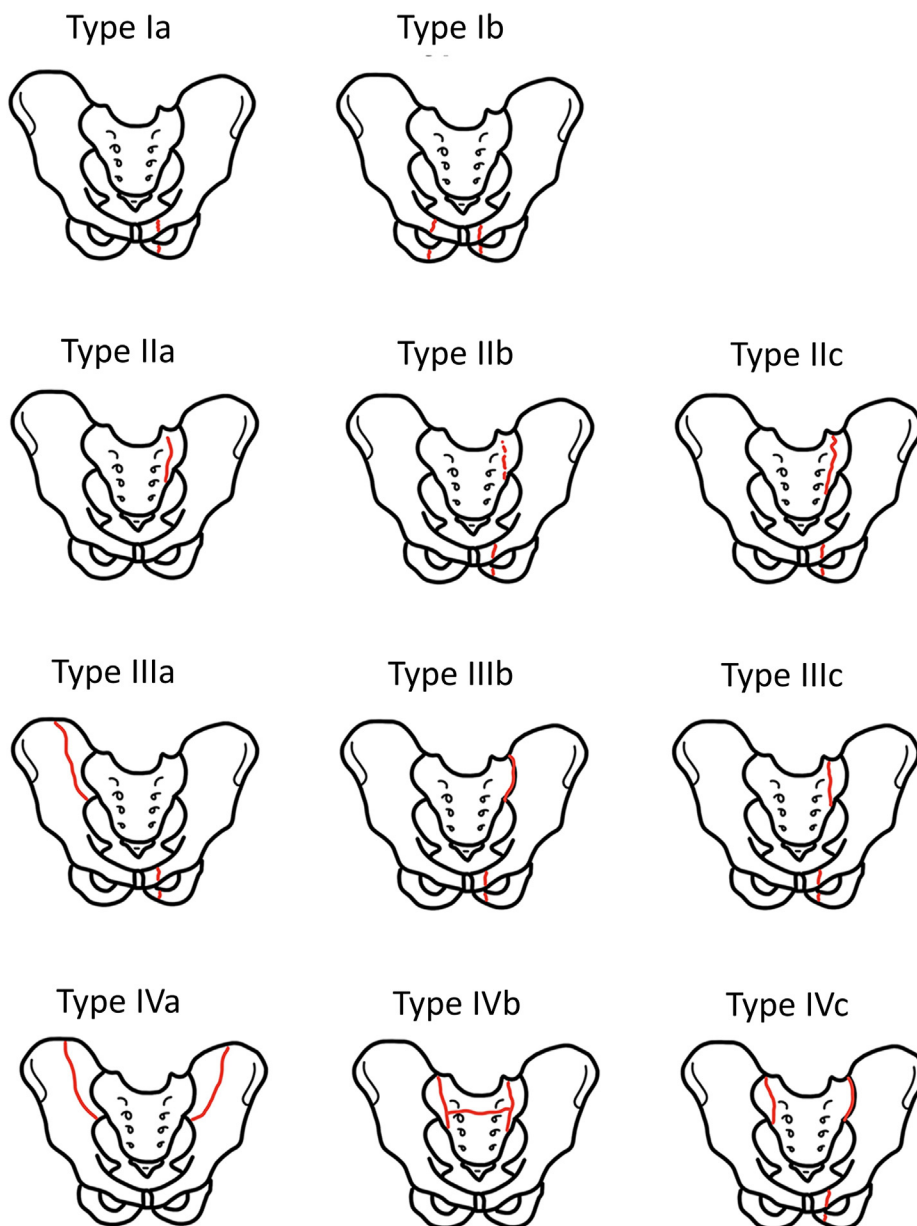
Type Ia Type Ib

Type IIa Type IIb Type IIc

Type IIIa Type IIIb Type IIIc

Type IVa Type IVb Type IVc

Fig. 1. Classification of fragility fractures of the pelvis; unilateral anterior pelvic ring disruption (type Ia); bilateral anterior pelvic ring disruption (type Ib); dorsal non-displaced posterior injury only (type IIa); sacral crush with anterior disruption (type IIb); non-displaced sacral, sacroiliac, or iliac fracture with anterior disruption (type IIc); displaced unilateral ilium fracture and anterior disruption (type IIIa); displaced unilateral sacroiliac disruption and anterior disruption (type IIIb); displaced unilateral sacral fracture combined with anterior disruption (type IIIc); bilateral iliac fractures or bilateral sacroiliac disruptions together with anterior disruption (type IVa); spinopelvic dissociation in combination with anterior disruption (type IVb); and combination of various posterior instabilities together with anterior disruption (type IVc).

compared between female patients with FFP type II and types III/IV, there was a tendency that female patients with FFP type II showed a decrease in SMI ($P = 0.057$, Cohen's $d = 0.90$) (Table 2). Individual mean HU in L3 in all (Table 1) and female (Table 2) patients with FFP type II and types III/IV were below the level defined as osteopenia (< 120HU) [30]. Mean value of SMI in the female patients with FFP type II was similar to the level defined as sarcopenia (< 38.5 cm^2/ m^2) [29].

Multiple logistic regression analysis was performed to identify determinant variables of posterior pelvic ring displacement in FFP using the data on demographics and CT-based markers on osteo-penia and sarcopenia. From the data from all patients, SMI was shown to be a potential determinant of fracture displacement (Table 3). When further analysis was performed using the data from

the female patients, SMI and age were selected as potential de-terminants of displaced FFP (Table 3).

4. Discussion

FFP commonly occur in frail individuals by a low-energy trauma [1]. Frailty includes decreased mass and strength of bone and muscle by aging [13], leading to osteoporosis and sarcopenia in the elderly. The combination of osteoporosis and sarcopenia in the elderly yields their predisposition to fragility fractures by falls [32]. Bone density reduction can produce principal strain patterns in the superior pubic rami, the greater sciatic notch, the supra-acetabular roof, and the sacral ala [33]. Significant decreases in both the cortical-surface and interior bone densities are found in those sites

Fig. 2. An axial slice of computed tomography at the level of the third lumbar vertebra showing a group of muscles including bilateral paraspinal (erector spinae, quadratus lumborum), psoas, rectus abdominis, transversus abdominis, and internal and external oblique muscles with the threshold set at −29 to 150 Hounsfield units.

with aging [4,34]. FFP generally occur with the typical fracture patterns in those sites as fracture lines follow areas of lowest sacral bone mass and highest strain. Similarly, this study showed that mean HU in L3 as a marker of osteopenia in the patients with FFP

were below the level defined as osteopenia (< 120HU) [31]. However, no difference in osteopenia was found between patients with non-displaced and displaced FFP. This indicates that osteopenia may play a minor role in displacement of the posterior pelvic ring in the early phase of FFP.

From the logistic regression analyses, higher SMI may be a potential determinant of displaced FFP in the early phase. Ricci et al [35] have investigated the load transmission within the non-fractured pelvic ring and the pelvis with single-sided anterior pelvic ring fracture under physiological loading during gait. Muscle forces and joint reaction forces are calculated by inverse dynamics and implemented in a finite element pelvis model including the joints. During a normal gait movement, the superior and inferior rami of the anterior pelvic ring show the highest stresses in accordance with the typical fracture site in the anterior pelvic ring. The pelvis with a superior ramus fracture increases stresses to the lower ramus with a slight increase in stresses around the sacroiliac joint. The pelvis with both superior and inferior rami fractures redirects the loads toward the back of the pelvis with the compression stress, especially on the sacrum, and results in significantly higher stresses around the sacroiliac joint, which may lead to fracture of the posterior pelvic ring. When pelvic ring fracture separates the pelvis in 2 parts, the fractured pelvis can be pulled by the surrounding muscles. Time interval between injury and the first CT examination was within 7 days in patients with FFP types III/IV in this study. Thus, relatively preserved mass and strength of the

Table 1
Comparison of demographic and radiologic data of all patients between non-displaced (type II) and displaced (types III/IV) fragility fractures of the pelvis with the first CT taken within 7 days after injury.

Variable	Type II (n = 34)		Types III/IV (n = 15)		P	Cohen's d
	Mean (SD)	95% CI	Mean (SD)	95% CI		
Age (yr)	81.9 (7.0)	79.4, 84.3	84.9 (8.3)	80.4, 89.5	0.190	0.41
Body mass index (kg/m^2)	21.0 (3.7)	19.7, 22.3	19.7 (3.8)	17.6, 21.9	0.230	0.35
Height (m)	1.51 (0.09)	1.47, 1.54	1.48 (0.09)	1.43, 1.53	0.325	0.31
Mean HU in L3	79.3 (47.7)	62.7, 96.0	69.3 (40.7)	46.7, 91.8	0.481	0.22
SMA (cm^2)	88.5 (14.7)	83.3, 93.6	98.8 (21.5)	86.9, 110.7	0.172	0.61
SMRA (HU)	24.7 (8.0)	21.7, 27.5	22.3 (7.9)	17.9, 26.7	0.336	0.30
SMI (cm^2/m^2)	39.0 (5.3)	37.1, 40.8	45.5 (10.4)	39.7, 51.3	**0.034**	**0.91**

Values highlighted in bold indicate statistical significance (P < 0.05) and large effect size (d ≥ 0.80). SD, standard deviation; CI, confidence interval; P, P-values; HU, Hounsfield units; L3, the third lumbar vertebral body; SMA, skeletal muscle area; SMRA, skeletal muscle radiation attenuation; SMI, skeletal muscle index; CT, computed tomography.

Table 2
Comparison of demographic and radiologic data of female patients between non-displaced (type II) and displaced (types III/IV) fragility fractures of the pelvis with the first CT taken within 7 days after injury.

Variable	Type II (n = 29)		Types III/IV (n = 13)		P	Cohen's d
	Mean (SD)	95% CI	Mean (SD)	95% CI		
Age (yr)	82.2 (7.4)	79.4, 85.0	84.9 (8.3)	80.4, 89.5	0.053	0.67
Body mass index (kg/m^2)	21.3 (3.7)	19.9, 22.8	19.7 (3.8)	17.6, 21.9	0.136	0.45
Height (m)	1.49 (0.08)	1.46, 1.51	1.48 (0.09)	1.43, 1.53	0.325	0.28
Mean HU in L3	86.9 (44.5)	69.9, 103.8	59.8 (40.7)	39.1, 80.5	0.059	0.65
SMA (cm^2)	84.8 (11.0)	80.7, 89.0	96.1 (21.8)	82.9, 109.2	0.204	0.75
SMRA (HU)	23.9 (7.8)	21.0, 26.9	21.6 (8.1)	16.7, 26.5	0.374	0.29
SMI (cm^2/m^2)	38.5 (5.0)	36.6, 40.4	45.2 (11.2)	38.5, 52.0	0.057	**0.90**

Values highlighted in bold indicate large effect size (d ≥ 0.80). SD, standard deviation; CI, confidence interval; P, P-values; HU, Hounsfield units; L3, the third lumbar vertebral body; SMA, skeletal muscle area; SMRA, skeletal muscle radiation attenuation; SMI, skeletal muscle index; CT, computed tomography.

Table 3
Logistic regression analysis for determinant variable of displaced fragile fractures of the pelvis.

Data from	Determinant	Odds ratio	95% confidence interval	P-value
All patients	Skeletal muscle index	1.121	1.025, 1.227	0.013
Female patients	Skeletal muscle index	1.124	1.022, 1.235	0.015
	Age	1.123	0.996, 1.265	0.057

muscles attached to the pelvis (eg, adductor, biceps femoris, gluteus, obturator, rectus femoris, and paraspinal muscles) potentially contribute to displacement of the posterior pelvic ring in the early phase of FFP.

Functional recovery is the primary goal of FFP treatment [1]. FFP in the elderly highly correlate with morbidity [36] and mortality [37]. Recent studies have indicated that radiographic FFP types may be unrelated to the patients' physical function [38] and surgical indications [39,40]. Yoshida et al [41] have reported that only 4.7% of the patients were indicated for surgery, even those with displaced FFP types III/IV, when pain control using analgesics and rehabilitation training by physical therapists started in patients with any type of FFP immediately after admission. Furthermore, the authors have suggested that inpatient rehabilitation could lead to better mobility and lower mortality compared with the findings in previous studies [42,43]. Another study has also shown that functional treatment which allows all patients with FFP to mobilize within pain limits in the first 10 days after injury results in no difference in functional outcome between patients with FFP type II and types III/IV [6]. From the present findings, functional conservative treatment during the acute phase after FFP types III/IV may be effective because patients in the early phase of displaced FFP likely has relatively preserved muscle mass. In case of patients with non-displaced FFP, frailty including sarcopenia by aging should be considered as a potential issue of treatment. A better understanding of the role of sarcopenia in FFP may be important to offer adequate conservative and surgical treatment options.

There are some limitations in this study. First, this was a retrospective study that enrolled a relatively small number of patients. The population studied was limited to Japanese patients examined at a single tertiary trauma center. The number of patients in this study may not be sufficient for detection of small associations. However, Cohen's d was large (≥ 0.8) when differences were statistically significant in this study. In addition, the fracture type distribution of this study, 69.4% as type II and 30.6% as types III/IV at the first CT examination, was similar to that in the previous studies [5,6]. Second, there were no longitudinal follow-up data. It remains uncertain how sarcopenia affects fracture progression from nondisplaced to displaced FFP. Third, sarcopenia and osteopenia were not evaluated by dual-energy X-ray absorptiometry. Because CT is commonly used for FFP classification, CT-based frailty markers may be useful in the clinical setting. Lastly, this study failed to employ MRI for accurate diagnosis of FFP type I.

5. Conclusions

Relatively preserved muscle indicated by higher SMI may be associated with displacement of the posterior pelvic ring in the early phase of FFP in the elderly with osteopenia. Future studies should focus on the role of sarcopenia in treatment selection and clinical course of FFP.

CRediT author statement

Shintaro Honda: Data curation, Investigation, Validation, Writing - review & editing. **Satoshi Ota:** Data curation, Validation, Writing - review & editing. **Shinnosuke Yamashita:** Data curation, Validation, Writing - review & editing. **Tadashi Yasuda:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Roles/ Writing - original draft, Writing - review & editing.

Conflicts of interest

The authors declare no competing interests.

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