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Original Article

Bone mineral density, limb muscle mass, muscle strength, and exercise capacity are reduced in female patients with distal radius fractures when the unaffected side grip strength is less than 18 kg

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ABSTRACT

Background: Prevention of domino effects after distal radius fractures is important for improving life expectancy. Fragility fractures secondary to falls are associated with decreased bone mineral density, muscle strength, and exercise capacity. Grip strength is one of the simplest and most useful tests to comprehensively judge muscle strength. The purpose of this study was to examine whether grip strength is associated with bone mineral density, limb muscle mass, muscle strength, and exercise capacity, by comparing patient backgrounds based on the presence or absence of grip weakness in female patients with distal radius fractures.

Methods: This study included women with distal radius fractures who visited our orthopedics outpatient department between April 2015 and April 2020. Bone mineral density, limb muscle mass, skeletal muscle mass index, muscle strength (grip strength on unaffected side and quadriceps muscle strength), the Timed Up and Go test, and the Two-Step test were evaluated six to eight weeks after injury. Patients were divided into two groups according to the cutoff value of grip strength (18–21 kg), and 90 age-adjusted and matched participants were compared and examined.

Results: At the cutoff value of 18 kg, a significant decrease in lumbar spine and total proximal femur bone mineral density ($p < 0.05$, $p < 0.05$), limb muscle mass and skeletal muscle mass index ($p < 0.01$, $p < 0.05$), quadriceps femoris muscle strength ($p < 0.01$), the Timed Up and Go test ($p < 0.05$), and the Two-Step test ($p < 0.01$), was observed in the grip-weakness group compared to that in the no-grip-weakness group.

Conclusions: In women with distal radius fracture and grip strength <18 kg on the unaffected side, bone mineral density, limb muscle mass, quadriceps femoris strength, and exercise capacity may be reduced. These results suggest reduced grip strength may be an indicator for further testing to prevent domino effects.

1. Introduction

The chain of fragility fractures caused by osteoporosis is referred to as the domino phenomenon of fractures (domino effect). Among these fragility fractures, the distal radius fracture is often the first fragility fracture; its incidence increases in women in their late 50s and peaks for those in their 60s and 70s, and this fracture is said to occur in a relatively active age group [1]. In addition, because individuals with distal radius fractures are at a 3.3-,1.9-, and 1.7 times higher risk of forearm bone fractures, hip bone fractures, and vertebral bone fractures, respectively [2], the risk of domino effects increases. Therefore, preventing domino effects after fractures of the distal radius is considered a critical issue for orthopedic surgeons.

The causes of distal radius fractures and secondary fragility fractures in older adults include bone fragility owing to decreased bone mineral density and bone quality, and falling due to decreased muscle mass, muscle strength, and exercise capacity. Approximately 90% of distal radius fractures in older adults are attributed to falls, and most hip fractures are also said to be caused by falls [3,4];

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thus, preventing falls might contribute to the prevention of domino effects after distal radius fractures.

Grip strength is one of the simplest and most convenient methods to measure muscle strength. A prospective cohort study found that reduced grip strength predicted an increased risk of fragility fractures of 1.57 times [5]. Grip weakness is also correlated with mortality [6]. Based on these studies, grip weakness may be factorial when evaluating fall and fracture etiology.

Therefore, this study aimed to investigate the background of women with distal radius fractures, including bone mineral density, limb muscle mass and muscle strength, and exercise capacity to examine whether grip weakness is an indicator of these factors by comparing them based on grip weakness on the unaffected side.

2. Materials and Methods

Between April 2015 and April 2020, all patients with distal radius fractures who visited the orthopedic surgery outpatient department of the City General Hospital were evaluated. Women over 40 years of age with distal radius fractures who had sustained injuries due to a fall and could walk independently were included in this study. Exclusion criteria were injury not related to falls; patients with thyroid disease, metabolic bone diseases, ureteral calculus, renal dysfunction, Cushing's syndrome, use of glucocorticoid hormone actives; previous treatment for malignancy; previous upper extremity fracture on the unaffected side; hemoglobinA1c $\geq$ 7.0, or diabetes. Patients who met the inclusion criteria provided written informed consent prior to participating in the study. This study was approved by the ethics committee of the City General Hospital.

Prior to the fracture treatment, patient's information was obtained via questionnaire comprising age, sex, body mass index (BMI; weight divided by height squared), and medical history, specifically fragility fracture history (including proximal femoral fracture, vertebral fracture, and six non-vertebral fractures, namely those of the distal radius, proximal humerus, rib, pelvic, clavicle, and lower leg, as well as a family history of proximal femoral fracture). Patients with distal radius fractures were treated conservatively with a cast or surgically with a volar locking plate, based on the 2012 and 2017 revised clinical practice guidelines for distal radius fractures [7,8]. At 6–8 weeks post-injury, bone mineral density was measured in the lumbar spine and total proximal femur, along with the limb muscle mass and skeletal muscle mass index (SMI) [9]. For muscle strength, the grip strength on the unaffected side and the strength of the quadriceps in the thigh were measured, whereas for exercise capacity, the Timed Up and Go (TUG) and Two-Step tests (2ST), which are the criteria for locomotive syndrome [10], were measured.

Measurements of bone mineral density in the lumbar spine and total proximal femur and of muscle mass in the limb were performed using dual-energy X ray absorptiometry (DXA) with a bone densitometer (PROGIDY FUGA, General Electric Health Care, Japan). Bone mineral density was expressed as the young adult mean value (YAM). Lumbar spine bone mineral density was measured in the 1st to 4th lumbar vertebra. Regarding the total proximal femoral bone mineral density, the bone mineral density of both left and right proximal femurs were measured and the average was calculated. Limb skeletal muscle mass was calculated by determining the body fat mass and the lean body mass using the DXA method and combining the values of the lean mass of the upper limbs and of the lower limbs. The SMI was corrected for limb muscle mass divided by the height squared. To evaluate muscle strength, grip strength was measured using a Grip-D T.K.K 5401 (Takei Scientific Instrument Co., Ltd., Tokyo, Japan). Grip strength of the unaffected side

Fig. 1. Using an Isoforce GT330, the patient sits on the seat and is secured with lumbar and thigh belts. The quadriceps femoris strength is then measured while the patient performs the isotonic, open kinetic chain exercise of knee extension.

was measured three times with the patient in a standing position and elbow extended, and the average value was considered. The quadriceps femoris muscle strength was also quantitatively measured using Isoforce GT330 (OG Wellness Technologies Co., Ltd., Okayama, Japan), which is an automatic exercise training device coupled with a measurement device (Fig. 1), and was calculated as the average value of the left and right quadriceps femoris muscle strength. In the TUG, the time (s) taken by each patient to stand up from an armchair, walk 3 m, turn, walk back, and sit on the chair was measured [11]. In the 2ST, the patients stood with their toes aligned at the standing line, took two steps as far as possible, and then aligned their feet to complete the test [12].

The cutoff value of the grip strength on the unaffected side was estimated by the following procedure. We divided the women participants (n = 124) with distal radius fracture before adjusting for age based on the presence or absence of osteoporosis according to the diagnostic criteria for primary osteoporosis (bone mineral density $\leqq$70% YAM for lumbar or total proximal femur) [13]; the estimated grip value (19.6 kg) was calculated by the receiver operating characteristic curve (specificity: 0.702, sensitivity: 0.652, area under the curve: 0.687) (Fig. 2). After the cutoff value of grip strength was set from 18 to 21 kg based on the estimated grip strength of 19.6 kg, each parameter was compared between the age-adjusted and age-matched grip-weakness (n = 45) and no-grip-weakness (n = 45) groups.

2.1. Statistical analysis

A per-protocol set analysis was used in this study. In the statistical test, propensity score matching using logistic regression analysis was used to adjust for age. Fisher's exact tests were used to compare the contingency table of gender and the occurrence rate of each event; BMI was compared by Student's t-test, because it followed a normal distribution. Mann–Whitney U tests were used to compare the other measured values, such as bone mineral density. All statistical analyses were performed using the modified graphical user interface of R (version 2.13.2., The R Foundation for Statistical Computing, Vienna, Austria), known as EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan). This

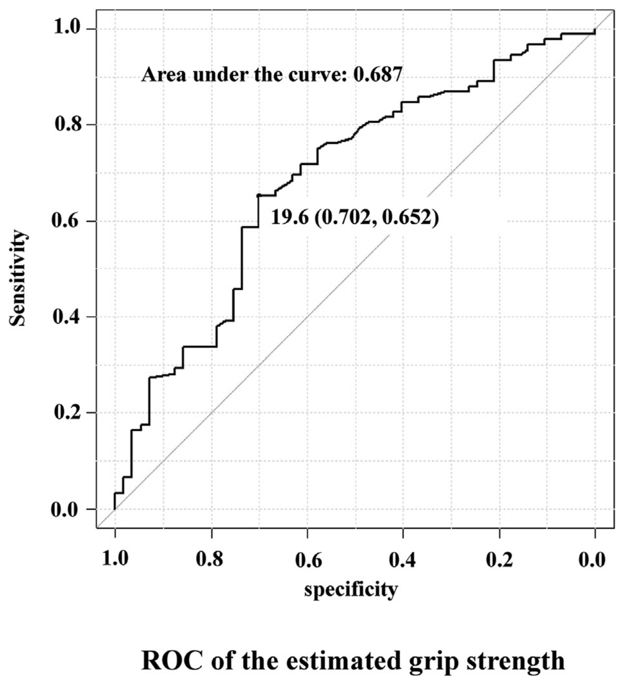

Fig. 2. Receiver operating characteristic curve that estimates the cutoff value of grip strength.

modified version of R Commander (version 1.8–4) was designed to add statistical functions that are frequently used in biostatistics. We considered $p < 0.05$ to indicate statistical significance.

3. Results

Significant differences were found in all parameters of bone mineral density, limb muscle mass, lower limb muscle strength, and exercise capacity at the cutoff value of 18 kg. The patients' backgrounds are shown in Table 1. There were no significant differences in BMI between the two groups at this cutoff value. In addition, there were no significant differences in the history of fragility fractures, vertebral compression fractures, parental hip fractures, or osteoporosis treatment. However, the rate of treatments history was low in both groups.

Lumbar and total proximal femoral bone density were significantly lower in the grip-weakness group (no-grip-weakness group vs. grip-weakness group: median, 86% vs. 78%, and 78% vs. 70%, respectively; both $p < 0.05$) (Fig. 3). Limb muscle mass and SMI were also significantly lower in the grip-weakness group compared to those in the no-grip-weakness group (no-grip-weakness group vs. grip-weakness group: median, 13,656 g vs. 12,694 g, and 5.89 g/m^2 vs. 5.52 g/m^2, respectively; $p < 0.01$, $p < 0.05$) (Fig. 4A). Regarding muscle strength, the quadriceps femoris muscle strength was significantly lower in the grip-weakness group compared to that in the no-grip weakness group (no-grip-weakness group vs.

Table 1
Comparison of patient background data.

		No-grip-weakness group (n = 45)	Grip-weakness group (n = 45)	p-value
Age (year)	Mean ± SD	71.4 ± 8.6	71.5 ± 8.7	p = 0.942
Body mass index (kg/m^2)	Mean ± SD	22.8 ± 3.8	26.1 ± 30.1	p = 0.144
Grip strength	Mean ± SD	22.2 ± 3.3	14.2 ± 2.9	p < 0.01**
Smoking history	yes	2 (4.4%)	4 (8.9%)	p = 0.677
Drinking history	yes	8 (17.8%)	11 (24.4%)	p = 0.477
History of fragile fractures	yes	14 (31.1%)	18 (40%)	p = 0.509
History of vertebral compression fractures	yes	8 (17.8%)	11 (24.4%)	p = 0.606
History of fracture treatments	yes	3 (6.7%)	4 (8.9%)	p = 1
Parental hip fractures	yes	2 (4.5%)	8 (17.8%)	p = 0.0897

Data are presented as numbers and percentages, unless otherwise stated. SD, standard deviation.

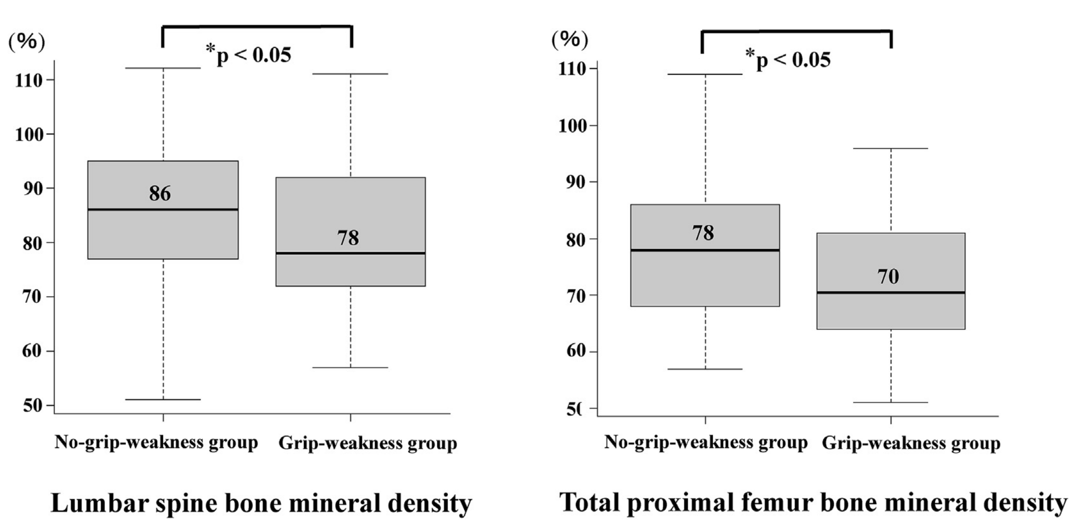

Fig. 3. Comparison of bone mineral density (lumbar spine and total proximal femur). Bone mineral density was expressed as the young adult mean value (YAM).

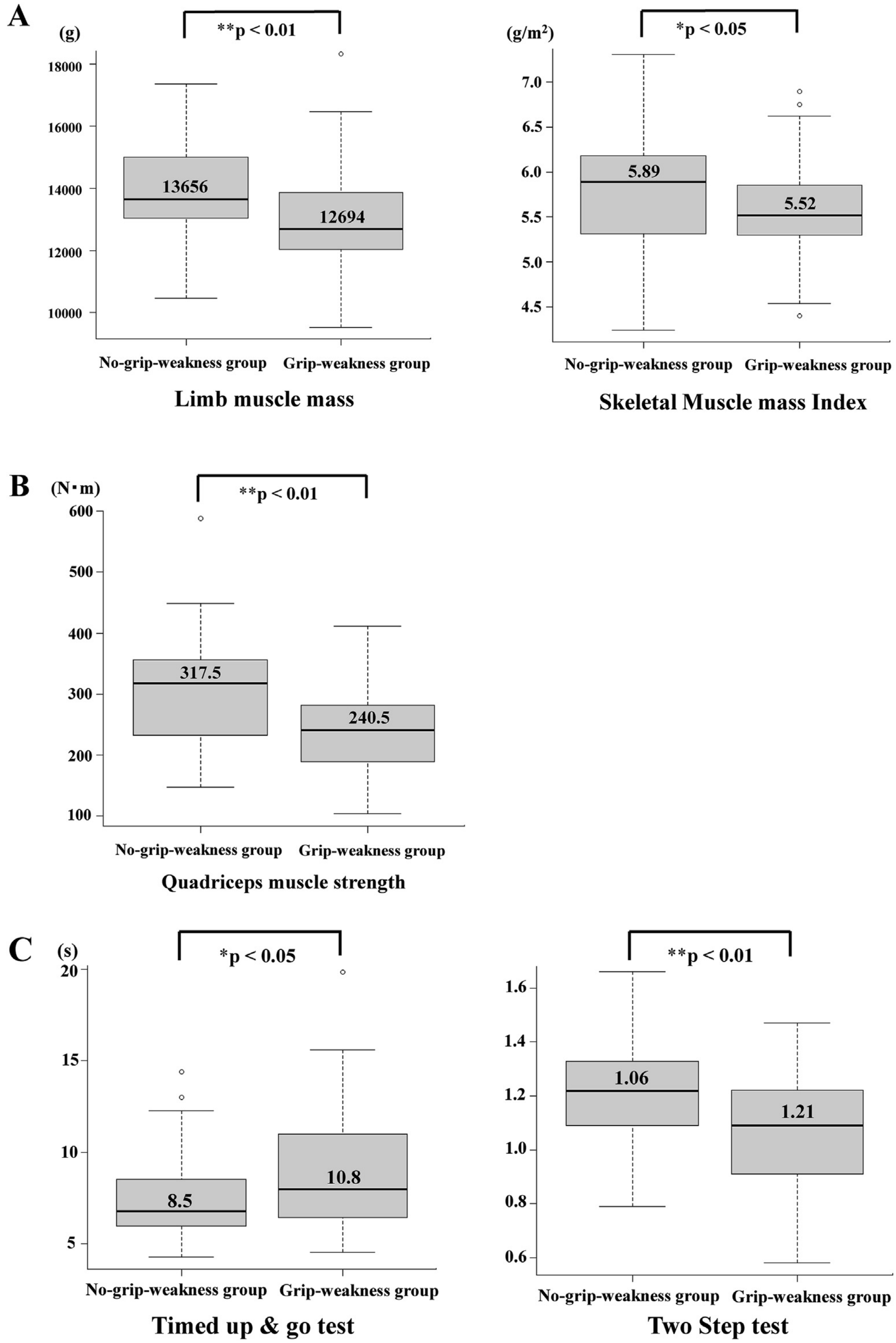

Fig. 4. Comparison of limb muscle mass, muscle strength and exercise capacity. A: Limb muscle mass and skeletal muscle mass index (SMI). B: Quadriceps muscle strength. C: Timed Up and Go (TUG) and Two-Step tests (2ST).

grip-weakness group: median, 317.5 N・m vs. 240.5 N・m; $p < 0.01$) (Fig. 4B). Furthermore, the TUG and 2ST as indicators of exercise capacity were also significantly lower in the grip-weakness group compared to those in the no-grip-weakness group (no-grip-weakness group vs. grip-weakness group: median, 8.5 s vs. 10.8 s and 1.06 vs. 1.21, respectively; $p < 0.05$, $p < 0.01$) (Fig. 4C).

4. Discussion

This study aimed to compare bone mineral density, limb muscle mass, SMI, lower limb muscle strength, and exercise capacity, based on the presence or absence of grip weakness, and examine whether grip strength can be an indicator of decreases in these factors that contribute to domino effects in older women with distal radius fractures.

Distal radius fractures in the older population are the third most common fracture after vertebral compression and proximal femur fractures, and are one of the most frequent fractures that occur mainly because of osteoporosis [14]. They often precede proximal humerus/femoral fractures among fragility fractures [1], and because they are likely to be the first fragility fracture, this is considered an opportunity for therapeutic intervention to prevent domino effects. Most patients with distal radius fractures have a falling mechanism of injury; in a study of 85 postmenopausal patients with distal radius fractures, 60% of the patients exhibited bone loss and 22.3% experienced a recurring fall one year after the fracture [15]. Based on this result, it is considered that patients are more likely to experience a secondary fracture from another fall after an initial fracture of the distal radius.

The results of this study showed that the bone mineral density in the lumbar spine and total proximal femur was significantly reduced in the grip-weakness group. Li et al. [16] reported that in a study of 120 postmenopausal women, the grip-weakness group (less than 20 kg in the dominant arm) exhibited significantly reduced bone mineral density in the lumbar spine, total proximal femur, and femoral neck. It has also been reported that grip strength correlates with vertebral, total proximal femur, and femoral neck bone density [17,18]. Based on the results of this study, we suggest that when a decrease in grip strength on the unaffected side is observed after a fracture of the distal radius, it is likely that bone mineral density has decreased and that secondary fractures might occur because of bone fragility. Therefore, bone mineral density should be actively measured in such patients. Additionally, if bone mineral density has decreased on DXA, treatment intervention is necessary to prevent osteoporosis.

Limb muscle mass and SMI were significantly decreased in the grip-weakness group. Ho et al. [19] reported that in a study of 120 patients with a history of hip fractures, appendicular SMI was positively correlated with hip bone mineral density. Pereira et al. [20] also reported that in a study of 198 male patients over 60 years old, patients with decreasing relative appendicular muscle mass were approximately eight times more likely to receive a diagnosis of abnormal bone mineral density compared with that of normal men. These results indicated that limb muscle mass and bone mineral density are correlated; patients with decreasing limb muscle mass might fall and sustain fracture. Therefore, not only bone mineral density but also limb muscle mass should be actively measured, such that in case of adverse outcomes, timely rehabilitation and nutrition therapy can be considered to prevent falls.

The quadriceps femoris muscle strength, the TUG, which reflects dynamic balance, and the 2ST, which comprehensively represents walking ability, were significantly decreased in the grip-weakness group compared with the no-grip-weakness group. A study of 167 healthy men and women aged 18–82 years reported a correlation between grip strength and quadriceps strength [21]. Based on the results of this study, it might be possible to predict muscle weakness in the lower limbs by simply measuring the grip strength of women after fractures of the distal radius. In addition, in a study of 6766 older adults aged 67–93 years, Fragala et al. [22] reported that decreased grip strength and quadriceps muscle strength were significantly associated with decreased walking speed. In a study comparing 128 women with distal radius fractures and controls, Fujita et al. [23] reported that patients with distal radius fractures had reduced grip strength and dynamic balance, suggesting that patients with distal radius fractures had preexisting decreased muscle strength and exercise capacity. Kobayashi et al. [24] also surveyed 88 Japanese individuals over 40 years old and reported that reduced grip strength could be a significant risk factor for future locomotive syndrome. Consistent with the results of these studies, our findings suggest that grip strength is closely associated with quadriceps femoris strength and exercise capacity.

Bone mineral density, limb muscle mass, SMI, lower limb muscle strength, and exercise capacity in women with distal radius fracture and grip weakness of less than 18 kg on the unaffected side were lower than in those without grip weakness. Bone mineral density is one of the indicators of treatment interventions for fall reoccurrence and secondary fractures, but only certain facilities have available devices for measuring bone mineral density. On the other hand, measuring grip strength is one of the simplest tests that can be performed anywhere. If the presence or absence of decreased grip strength on the unaffected side of women with distal radius fracture is an indicator for a decrease in bone mineral density, limb muscle mass, lower limb strength, and exercise capacity, it might be possible to implement effective treatment interventions to prevent domino effects. In other words, if decreased grip strength on the unaffected side is present, it should be followed with a test for bone mineral density, limb muscle mass, lower limb muscle strength and balance, to confirm the diagnosis of locomotive syndrome. In cases where a decrease in these parameters is observed, it is necessary to actively intervene with treatment to prevent falls and further fractures.

This study has some limitations. First, the number of cases was small, which may have affected the results of the study. It is therefore necessary to increase the sample size and continue the investigation in the future. Second, because the tests were not performed directly after the injury but 6–8 weeks later, rehabilitation may have affected the results. However, the grip strength of the hand on the unaffected side was measured, which was probably less affected by rehabilitation than that on the affected side. Since there is no specific guidance on rehabilitation or exercise for the trunk or lower limbs, its influence on exercise capacity is likely relatively low. Third, only the grip on the unaffected side was measured; we did not factor in whether the grip was of the dominant or nondominant hand, the influence of which might be of concern. In general, 10% of all individuals are left-handed [25], and only left-sided fractures were evaluated; thus, the unaffected side was likely the dominant side in this study. However, it might be necessary to examine grip only on the dominant side as the number of cases increase. Fourth, regarding the bone mineral density measurement of the lumbar spine, collapsed vertebral body was included in 3 no-grip-weakness and in 4 grip-weakness cases. However, all vertebral bodies were only mildly collapsed, so the influence on lumbar spine bone mineral density is likely relatively low.

In conclusion, if the grip strength on the unaffected side is below 18 kg in women with distal radius fractures, the bone mineral density, limb muscle mass, lower limb muscle strength, and exercise capacity might be decreased. Therefore, these findings suggest reduced grip strength may warrant further testing and active intervention with timely treatment, thereby preventing domino effects by early examination after a distal radius fracture.

5. Consent statement

All patients included in this study provided written informed consent prior to participating in the study. This study was approved by the ethics committee of the City General Hospital.

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Declaration of competing interest

The authors declare that there are no conflicts of interest to report.

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