Annals of Physical and Rehabilitation Medicine 66 (2022) 101680

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com

Original article

Association between vertebral fragility fractures, muscle strength and physical performance: A cross-sectional study

Melise Jacon Peres-Ueno[a,*], Luana Leticia Capato[b], Jaqueline Mello Porto[a], Isabela Ferreira Adão[c], Jamilly Maciel Gomes[d], Carlos Fernando Pereira da Silva Herrero[e], Marcello Henrique Nogueira-Barbosa[f], Francisco Jose Albuquerque de Paula[g], Eduardo Ferrioli[g], Daniela Cristina Carvalho de Abreu[c]

[a] *Program in Rehabilitation and Functional Performance, Ribeirão Preto School of Medicine, University of São Paulo (USP), Ribeirão Preto (SP), Brazil*
[b] *Postgraduate Program in Rehabilitation and Functional Performance, Ribeirão Preto School of Medicine, University of São Paulo (USP), Ribeirão Preto (SP), Brazil*
[c] *Department of Health Sciences, Ribeirão Preto School of Medicine, University of São Paulo (USP), Ribeirão Preto (SP), Brazil*
[d] *Postgraduate Program in the Department of Internal Medicine, Ribeirão Preto Medical School, University of São Paulo (USP), Ribeirão Preto, SP, Brazil*
[e] *Department of Orthopedics and Anesthesiology at the Ribeirão Preto Medical School of the University of São Paulo (USP), Ribeirão Preto (SP), Brazil*
[f] *Department of Medical, Imaging, Hematology and Oncology at the Ribeirão Preto Medical School of the University of São Paulo (USP), Ribeirão Preto (SP), Brazil*
[g] *Department of Internal Medicine at the Ribeirão Preto Medical School of the University of São Paulo (USP), Ribeirão Preto (SP), Brazil*

A R T I C L E   I N F O

Article History:
Received 12 December 2021
Accepted 29 April 2022
Available online xxx

Keywords:
OSTEOPOROSIS
SARCOPENIA
OLDER ADULTS
PHYSICAL PERFORMANCE
FRAILTY
REHABILITATION

A B S T R A C T

Background: Few studies have investigated the association between vertebral fragility fractures and lower limb muscle strength and physical performance in women with low bone mass.
Objectives: To explore whether the presence of vertebral fracture is independently associated with poor physical performance and decreased lower limb muscle strength. To understand whether lower limb muscle strength is associated with physical performance in women with vertebral fracture.
Methods: Older women with low bone mass were divided into 2 groups: no vertebral fracture (NF) and presence of vertebral fragility fracture (VFF). Physical performance was evaluated using the Five Times Sit to Stand (5TSS) test, the Timed Up and Go (TUG) test and a 5m walk test (5MWT). Lower limb muscle strength was assessed using an isokinetic dynamometer.
Results: We included 94 women with low bone mass (mean age 71.6 [SD 5.7] years, time since menopause 24.4 [7.1] years, mean BMI 27.5 [5.1] kgm^{-2}). VFF was only associated with low peak hip abductor torque ($p = 0.001$) after adjustments. In the VFF group (n= 47), each 1 $Nmkg^{-1}$ increase: in knee extensor torque was associated with improved 5MWT ($p = 0.005$), TUG ($p = 0.002$) and 5TSS ($p = 0.005$) performances; in knee flexor torque was associated with improved 5MWT speed ($p = 0.003$) and TUG time ($p = 0.006$); in hip abductor torque was associated with improved 5MWT speed ($p = 0.003$); and in hip extensor torque with improved TUG time ($p = 0.046$).
Conclusion: VFF was associated with reduced hip abductor strength in older women. However, the number of vertebral fractures influenced the association. Additionally, lower limb muscle strength was associated with physical performance, regardless of the clinical characteristics of the fractures. Therefore, strength and power training programs for the lower limbs could improve physical performance.

Introduction

Vertebral fragility fracture (VFF) is the most common fragility fracture in women with low bone mass, and is usually the first osteoporotic fracture to occur [1]. Most VFF occur during everyday activities such as climbing stairs, carrying weight or leaning forward [2] and are associated with decreased participation in activities of daily living [3], back pain [4], balance impairments [5], impaired gait [6], postural changes [7], reduced quality of life [8] and mortality [9]. The risk of future fractures doubles in the year after the initial vertebral fracture [10]; therefore, early intervention and adequate rehabilitation are essential to improve the quality of life of these women and reduce the risk of morbidity and mortality.

Current studies have shown a strong association between osteoporosis and sarcopenia [11, 12]. Muscle strength is commonly reduced in women with reduced bone mass because of muscle-bone interaction: the bone response is strongly dependent on the load

* Corresponding author at: Ciências da Saúde, Universidade de São Paulo Faculdade de Medicina de Ribeirão Preto, Ribeirao Preto, São Paulo, Brazil
E-mail address: meliseperes@usp.br (M.J. Peres-Ueno).

https://doi.org/10.1016/j.rehab.2022.101680
1877-0657/

applied by the muscle [13]. Moreover, lower limb muscle mass is further reduced in women with VFF [14] and measurements of muscle mass suggest the prevalence of sarcopenia is higher than in women without VFF [15]. Considering that strength loss occurs more rapidly than loss of muscle mass during the aging process, it is expected that the decline in muscle strength is more rapid in women with VFF; however, this hypothesis has not yet been tested. Reduced lower limb muscle strength may explain poorer performance in clinical tests in women with VFF [16, 17]. Reduced lower limb muscle strength can be a trigger for postural changes such as increased trunk flexion during certain tasks that require more muscle strength (sit to stand from a chair). Previous studies have shown an association between lower limb muscle strength and functional tests in older adults in the community [18, 19].

In clinical practice, different functional tests are used to assess physical performance in older adults, such as the Five Times Sit to Stand (5TSS) test [20], the Timed Up and Go (TUG) test [21], and timed walk tests [22]. These tests assess simple tasks, such as walking, to more challenging tasks that include getting up from a chair and performing a 180° turn. The assessment of physical performance is essential in clinical practice since poor physical performance is associated with impaired function or disability in ADLs [17], as well as an increased risk of falls [23].

However, few studies have explored the association between the presence of VFF and lower limb muscle strength, or the association between muscle strength and physical performance in women with low bone mass. Understanding whether the presence of a VFF is associated with a decrease in lower limb strength and how much this strength contributes to physical performance would help clinicians 1) to choose appropriate exercise interventions to reduce the risk of a new fracture and improve the individual's quality of life and 2) to choose appropriate clinical tests for the evaluation and follow-up of these women.

The primary aim of this study was to compare physical function and lower limb muscle strength in women with low bone mass, with and without VFF. The second aim was to explore whether the presence of VFF in women with low bone mass is independently associated with poor physical performance and decreased lower limb muscle strength. The third aim was to understand whether lower limb muscle strength is associated with physical performance regardless of vertebral fracture characteristics and other covariates in women with VFF. We tested 3 hypotheses:1) physical performance and muscle strength are lower in women with than women without VFF, 2) that the presence of vertebral fracture is associated with poorer physical performance and lower lower limb muscle strength and 3) that lower limb muscle strength explains poor physical performance in women with VFF.

Methods

Study design

We conducted a cross-sectional study of older women followed at the Metabolic Bone Disease Outpatient Clinic of the Ribeirao Preto Medical School of University of São Paulo (HC-FMRP/USP) from January 2018 to November 2019. The study was approved by the Ethics and Research Committee of the HC-FMRP-USP (CAAE: 72799917.7.0000.5440). All participants signed an informed consent form for participation, which was also approved by the local ethics committee. The study is reported according to the Strengthening Reporting of Observational Studies in Epidemiology (STROBE) guidelines [24].

Participants took part in 2 assessment days. On Day 1, we collected data through interviews to characterize the sample, and took weight and height measurements to calculate the body mass index (BMI). Assessment of bone mineral density and vertebral fracture was then conducted at the radiology department of HC-FMRP / USP. On Day 2, participants underwent physical performance and muscle strength tests. All clinical assessments were performed by 4 researchers who were blinded to vertebral fracture diagnosis.

Participants

Inclusion criteria were women, aged between 60 and 80 years, with low bone mass diagnosed by dual-energy X-ray absorptiometry (DEXA), functionally independent, at least 12 months post menopause, able to understand test instructions and with a bone mineral density (BMD) *T*-score in the lumbar spine and/or neck of femur < -1.0 standard deviation (SD) . Exclusion criteria were memory impairment that interfered with the performance of daily activities (self-report), use of assistive devices for walking, presence of uncontrolled serious illnesses, continuous use of psychotropic drugs, decompensated type-2 diabetes, loss of bone mass secondary to other diseases, presence of vertebral stenosis or previous spinal surgery. After inclusion, participants could be excluded if they did not understand the test instructions or if they did not perform all the clinical and muscle strength tests.

We divided the sample into 2 groups based on the panoramic radiographic images of the thoracic and lumbar spine: low bone mass and no vertebral fracture (NF) and low bone mass and vertebral fragility fracture (VFF).

Subjective data

We collected the following information through interview to characterise the sample: age, time since menopause, history of falls within the last 6 months, level of physical activity, presence of back pain, history of chronic diseases and history of non-vertebral fractures.

We used the short version of the International Physical Activity Questionnaire (IPAQ) to assess the level of physical activity; this questionnaire has been translated and validated for use in Brazil [25]. Participants were classified as inactive, moderately active and high level of physical activity according the their score.

Bone mass assessment

Participants underwent a lumbar and neck of femur DEXA test to evaluate their BMD. A Hologic brand device (Discovery Wi, QDR Series, Waltham, MA, USA) was used and the same protocol and routine were used for all participants. This device has an error level of 1.84%. Those with BMD *T*-scores < -1.0 SD were included in the analysis. We used a *T*-score ≤ -2.5 SD to diagnose osteoporosis and a *T*-score between -1.0 and -2.5 SD to diagnose osteopenia.

Anthropometric assessment

We assessed body weight with a digital anthropometric scale and participants wearing light clothes. Height was measured by a wall stadiometer, with participants barefoot, standing with feet together and heels, hips and head in contact with the wall. They were instructed to keep the eyes fixed in the horizontal axis. BMI was calculated as the ratio between body weight (kg) and height (m) squared.

Vertebral fracture assessment

To assess the presence of a vertebral fracture, a panoramic radiograph of the thoracic and lumbar spine acquired using the CR Long Length Vertical Imaging System (Kodak Direct View, Carestream Health, Rochester, NY, USA) was performed. Lateral images were acquired at a distance of 2 m from the radiographic device. As previously reported [26], participants stood with their arms resting on a support, the shoulders flexed at 30° and elbows slightly bent. The method developed by Genant et al. [27] was used to define and classify the vertebral fracture.

The degree of thoracic kyphosis was determined with the Cobb angle, assessed on the radiographic image of the thoracic spine, considered as the gold standard to assess the degree of kyphosis. The beginning of the thoracic curve was marked by drawing a line from the upper edge of the vertebral body from T4 to the lower edge of T12. The Cobb angle was determined by the angle formed by the crossing point of perpendicular lines drawn from these lines. An angle greater than 50° was considered as thoracic hyperkyphosis [28].

Physical performance tests

The 5TSS was performed with a standard chair without arms: participants sat with their feet flat on the floor, back against the back rest and arms crossed in front of their chest. They were instructed to get up and sit down from the chair 5 times in a row, as quickly as possible, and the time taken to complete the task was recorded [20]. The test was repeated twice with an interval of at least 1 minute between repetitions, the mean value was used in the analysis.

For the TUG test, participants started in a sitting position on a chair with their feet on the floor and back against the back support. They were instructed to get up from the chair, walk 3 meters at their usual speed, turn, return to the chair and sit [21]. The test was performed 3 times, and the mean value was used for the analysis.

For the 5MWT, participants were asked to walk a distance of 8 meters at their usual speed. The time taken to perform the task was recorded in the central 5 meters of the walk (using a stopwatch) to avoid the acceleration and deceleration phases [22]. The test was performed 3 times and gait speed was calculated, the mean value of the 3 trials was used in the analysis.

These tests have been shown to be reliable in older adults [20, 21, 22].

Muscle strength assessment

Peak torque measurements of the hip and knee flexor/extensor muscles and hip abductor/adductor muscles were performed using an isokinetic dynamometer (Biodex System 4 Pro, New York, USA) that was calibrated weekly according to the manufacturer's recommendations. The muscles of the dominant lower limb (self-reported preferred limb to kick a ball) were evaluated [29].

Participants performed a 5-minute warm up on an exercise bike (Athletic Extreme). The evaluation protocol consisted of 3 maximum, voluntary, isometric contractions (MVICs) lasting 5 s with an 30 s interval between each. The data were processed by the device software: we collected the maximum peak torque of the 3 MVICs, which were later normalized to each participant's body weight (Nm.kg^{-1}). Peak torque was normalized by body weight to more accurately represent muscle performance in relation to the participant's mass [30]. Verbal encouragement was given throughout the test, and the participants were instructed to perform the contractions as strongly and as quickly as possible [31]. Isometric contractions were performed because they are considered as safe and more reproducible in older people who may have limited range of motion and pain and may use compensations during concentric contractions [32]. Since the evaluation was blinded and randomized, the order of test execution was trunk-hip-knee for one participant and knee-hip-trunk for the next participant, and so on. For the hip and knee tests, participants were positioned according to the description by Porto et al. [33].

Statistical analysis

Statistical analysis was performed using SPSS (version 17.0 – SPSS Inc.; IBM, Chicago, IL, USA) and $p<0.05$ was considered significant. To characterize the sample, data were described by means, standard deviations (SD) and percentages. An unpaired *t* test was used to compare VFF and NF groups. The association between the presence of a vertebral fracture (independent variable) and performance in clinical tests (dependent variables) was assessed with a multiple linear regression model adjusted for possible confounding factors. The association between muscle strength (independent variable) and performance in clinical tests (dependent variables) in women with VFF was assessed with a multiple linear regression model adjusted for possible confounding factors. To determine which covariates should be included in the statistical models, Pearson correlation was performed. Accordingly, age, height, number of fractures, number of falls and presence of back pain were considered as confounding factors for the association between the presence of vertebral fracture, physical performance in the clinical tests and muscle strength in the whole sample (n=94). Additionally, age, height, number of fractures and number of falls were considered as confounding factors for the association between muscle strength and performance in clinical tests in the VFF group (n=47). Associations were determined by the non-standardized regression coefficient (β), and the performance of the final model was evaluated by Nagelkerke's R^2, which estimates the variance of the results explained by the model. The sample power (n=94) of 99% was calculated considering R^2= 0.24 and an effect size (0.49) obtained in the analysis between the presence of VFF and the 5MWT, using G*Power software, version 3.1.92 (Universitat Kiel; Kiel, Germany).

Results

We interviewed 245 women who attended the Metabolic Bone Disease Outpatient Clinic of the Ribeirao Preto Medical School. Of these, 136 were excluded: 31 refused to participate; 34 had severe locomotor deficits or required a wheelchair for mobility; 32 had secondary bone loss (7 with rheumatoid arthritis 7 and 21 with osteogenesis imperfecta); 10 had severe cardiovascular disease; 12 had neurological disorders (5 with Parkinson's and 7 with Alzheimer's disease); 8 had impaired understanding or memory; and 9 had a lumbar spine BMD *T*-Score > -1.0 SD. Of the 109 women included, 15 participants were subsequently excluded: 7 refused to continue the evaluations; 2 died; 2 were diagnosed with cancer and 4 had hip surgery due to a fall. Therefore, 94 women were included in the final analysis. Of these, 47 had no fracture (NF) and 47 had a vertebral fragility fracture (VFF).

General features

Participant characteristics are shown in Table 1. Mean age of the 94 women was 71.6 (SD 5.6) years, time since menopause was 24.4 (7.0) years and mean BMI was 27.5 (5.1) kgm^{-2}. None of the women had a high level of physical activity, 56% had a low level of physical activity, and 44% a moderate level. A total of 71% had back pain and the mean degree of kyphosis was 49.1 (16.3) degrees. Mean lumbar BMD *T*-score was -2.15 SD, 65% of women had osteoporosis and 35% had osteopenia. A total of 44% reported a fall in the last year.

Women in the VFF group were significantly older (p = 0.005), with a longer time since menopause (p = 0.023), shorter height (p = 0.001) and more complaints of back pain (p = 0.041) than the NF group. In addition, the VFF group had lower lumbar spine BMD (p = 0.010), more women with osteoporosis (47%) and more reported falls in the last year compared to the NF group (p = 0.001).

Analysis of the clinical characteristics of the vertebral fractures in the VFF group (Table 2) found a mean number of fractures of 2.3 (SD 1.6), with a higher prevalence of women with 1 to 2 fractures (68%): 38% of the fractures were located in the thoracic region and 34% in the lumbar region, and 28% were in several spinal regions.

Table 1
Sample Characteristics

Variables	Total sample (n=94)	NF (n=47)	VFF (n=47)	eta^2	*p* value
Age (years)	71.6 (5.7)	69.98 (4.9)	73.2 (5.9)	0.08	0.005*
Time of menopause (years)	24.4 (7.1)	22.8 (7.6)	26.0 (5.9)	0.05	0.02*
Weight (kg)	63.5 (12.2)	64.2 (11.6)	62.7 (12.9)	0.004	0.55
Height (m)	1.5 (0.1)	1.5 (0.1)	1.5 (0.1)	0.11	0.001*
BMI (kgm^{-2})	27.5 (5.1)	27.1 (4.6)	27.9 (5.5)	0.006	0.47
Physical Activity Level				0.004	0.54
Low n (%)	53 (56)	28 (51)	25 (53)		
Moderate n (%)	41 (44)	19 (40)	22 (47)		
Presence of back pain				0.05	0.04*
Yes n (%)	67 (71)	29 (62)	38 (81)		
No n (%)	27 (30)	18 (39)	9 (19)		
Degree of thoracic kyphosis (°)	49.12 (16.28)	46.87 (14.38)	51.38 (17.84)	0.02	0.18
Lumbar BMD (*T*-score)	-2.15 (1.03)	-1.88 (0.85)	-2.42 (1.13)	0.06	0.01*
Osteoporosis n (%) Osteopenia n (%)	61 (65) 33 (35)	9 (19) 38 (81)	22 (47) 25 (53)		
Fall during the past 12 months n (%)	41 (44)	15 (32)	26 (62)	0.06	0.001*

* $p < 0.05$, NF vs VFF
Values expressed as means (SD) and frequencies. BMD: bone mineral density; BMI: body mass index; NF: no fracture; VFF: vertebral fragility fracture

Physical performance and muscle strength

Table 3 shows the mean values of the clinical tests and the peak torque of the muscles evaluated for the total sample and the NF and VFF groups.

The physical performance of the VFF group was poorer than the NF group, with longer TUG ($p < 0.001$) and 5TSS ($p = 0.03$) performance times and slower 5MWT speed ($p < 0.001$).

In addition, the VFF group had a lower peak torque for all lower limb muscles evaluated, except for the hip adductors.

Association between VFF, physical performance and muscle strength

The results of the multiple linear regression are presented in Table 4.

The unadjusted model was statistically significant and indicated that the presence of VFF was associated with slower 5MWT ($p < 0.001$), TUG ($p < 0.001$) and 5TSS performances ($p = 0.030$). Regarding muscle strength, the presence of VFF was associated with lower peak torque of the hip flexors ($p = 0.02$), extensors ($p = 0.02$) and abductors ($p < 0.001$) and the knee flexors ($p = 0.02$) and extensors ($p = 0.001$).

When the statistical model was adjusted for age, height, number of falls and presence of pain (adjustment model 3), the presence of VFF was associated with slower gait speed, longer TUG performance time and weaker hip abductors and knee extensors. However, when the number of fractures was included in the adjustment model (adjustment 4), VFF was associated with weaker hip abductors ($p = 0.001$) and the presence of VFF accounted for 38% of the variance in peak hip abductor strength.

Table 2
Characteristics of vertebral fractures in the VFF group (n=47)

Variables	
Number of fractures, mean (SD)	2.3 (1.6)
Presence of 1-2 VF, n (%)	32 (68)
Presence of 3-4 VF, n (%)	10 (21)
> 5 VF, n (%)	5 (11)
VF location	
Thoracic, n (%)	18 (38)
Lumbar, n (%)Multiple, n (%)	16 (34) 13 (28)

VFF= vertebral fragility fracture

Association between muscle strength and physical performance in women with VFF

Multiple linear regression was used to verify the association between lower limb muscle strength and physical performance in women with VFF (Table 5). We present results of the unadjusted statistical model and the model adjusted for age, height, number of falls and number of fractures.

5MWT

The unadjusted model was statistically significant and showed a positive association between the 5MWT and peak torque of the hip extensors and abductors, and knee flexors and extensors. For each 1 $Nmkg^{-1}$ increase in peak torque of the hip extensors and abductors, knee flexors and knee extensors, mean 5MWT speed increased respectively by 0.4 m/s, 0.5 m/s, 0.5 m/s and 0.3 m/s.

Adjustment for age, height, number of falls and number of fractures in the regression model showed that 5MWT explained 43% of the variance in peak force of the hip abductors ($p = 0.003$), 42% of the variance at peak strength of the knee flexors ($p = 0.003$) and knee extensors ($p < 0.001$). For each 1 $Nmkg^{-1}$ increase in peak torque of the hip abductors, knee flexors and extensors, mean 5MWT speed increased respectively by 0.4 m/s, 0.5 m/s and 0.3 m/s.

TUG

The unadjusted model was statistically significant and showed a negative association between TUG performance time and peak torque of the hip extensors and abductors, knee flexors and knee extensors. For each 1 $Nmkg^{-1}$ increase in peak torque of the hip extensors and abductors, knee flexors and knee extensors, TUG time reduced respectively by 6.2 s, 6.2 s, 7.9 s and 5.3 s.

Adjustment for age, height, number of falls and number of fractures in the regression model showed that the result of the TUG test explained 32% of the variance in peak strength of the hip extensors ($p = 0.46$), 38% for knee flexors ($p = 0.006$) and 41% for knee extensors ($p = 0.002$). For each 1 $Nmkg^{-1}$ increase in peak torque of the hip extensors, knee flexors and extensors, TUG time decreased respectively by 4.5 s, 7.71 s and 4.81 s.

5TSS

The unadjusted model was statistically significant and showed a negative association between the 5TSS and peak torque of hip

Table 3
Results of the physical performance and muscle strength tests

Clinical Tests	Total sample (n=94)	NF (n=47)	VFF (n=47)	*eta*^{2}	*p* value
5TSS (s)	14.4 (4.3)	13.4 (3.8)	15.3 (4.6)	0.05	0.03*
TUG (s)	11.4 (4.1)	9.4 (2.0)	13.4 (4.6)	0.2	< 0.001*
5MWT (m.s^{-1})	1.0 (0.3)	1.1 (0.3)	0.9 (0.3)	0.14	< 0.001*
Peak torque (Nmkg^{-1})					
Hip flexors	0.40 (0.20)	0.45 (0.2)	0.35 (0.22)	0.06	0.02*
Hip extensors	0.92 (0.36)	1.00 (0.4)	0.83 (0.28)	0.06	0.02*
Hip abductors	0.54 (0.29)	0.71 (0.2)	0.38 (0.28)	0.3	< 0.001*
Hip adductors	0.70 (0.29)	0.65 (0.3)	0.75 (0.30)	0.02	0.14
Knee flexors	0.62 (0.25)	0.68 (0.3)	0.56 (0.22)	0.05	0.02*
Knee extensors	1.23 (0.46)	1.39 (0.5)	1.08 (0.39)	0.1	0.001*

* $p < 0.05$, NF vs VF
Values expressed as means (SD). 5TSS: five times sit to stand; 5MWT: five metre walk test; NF: no fracture; TUG: Timed up and go; VF: vertebral fracture

Table 4
Multiple Linear regression of the presence of vertebral fracture (independent variable), physical performance and muscle strength (dependent variables) (n=94)

	Unadjusted model			Adjustment 1			Adjustment 2			Adjustment 3			Adjustment 4		
Clinical tests	ß	R^2	*p* value	ß	R^2	*P* value	ß	R^2	*p* value	ß	R^2	*P* value	ß	R^2	*P* value
5MWT (m.s^{-1})	-0.21	0.14	< 0.001*	-0.12	0.28	0.03*	-0.12	0.28	0.03	-0.13	0.30	0.02*	-0.11	0.30	0.17
TUG (s)	4.01	0.25	< 0.001*	3.25	0.30	< 0.001*	3.09	0.31	< 0.001*	3.12	0.31	< 0.001*	1.75	0.34	0.11
5TSS(s)	1.90	0.05	0.03*	1.63	0.06	0.09	1.50	0.07	0.12	1.75	0.09	0.07	1.35	0.10	0.32
Peak torque (Nmkg^{-1})															
Hip flexors	-0.10	0.06	0.02*	-0.08	0.07	0.06	-0.07	0.13	0.13	-0.07	0.13	0.11	-0.06	0.13	0.31
Hip extensors	-0.18	0.06	0.02*	-0.14	0.08	0.08	-0.13	0.09	0.11	-0.15	0.10	0.07	-0.20	0.11	0.07
Hip Abductors	-0.33	0.32	< 0.001*	-0.31	0.33	< 0.001*	-0.29	0.38	< 0.001*	-0.29	0.38	< 0.001*	-0.26	0.38	0.001*
Hip adductors	0.09	0.02	0.14	0.11	0.03	0.09	0.12	0.04	0.08	0.11	0.049	0.11	0.01	0.07	0.92
Knee flexors	-0.11	0.05	0.02*	-0.10	0.07	0.09	-0.10	0.07	0.10	-0.10	0.08	0.08	-0.15	0.09	0.06
Knee extensors	-0.31	0.12	0.001*	-0.24	0.16	0.012*	-0.23	0.17	0.02*	-0.25	0.18	0.01*	-0.22	0.18	0.12

* $p < 0.05$
Adjustment 1: age and height; Adjustment 2: adjustment 1 + number of falls; Adjustment 3: adjustment 2 + presence of back pain; Adjustment 4: adjustment 3 + number of vertebral fractures.
5TSS: five times sit to stand; 5MWT: five metre walk test; TUG: Timed up and go.

Table 5
Multiple Linear regression between muscle strength (independent variable) and physical performance (dependent variables) in older women with VFF (n=47)

	Unadjusted model			Adjustment 1			Adjustment 2			Adjustment 3		
5MWT (m/s)	ß	R^2	*p* value	ß	R^2	*p* value	ß	R^2	*p* value	ß	R^2	*p* value
Hip flexors	0.26	0.04	0.14	0.17	0.29	0.28	0.15	0.30	0.36	0.14	0.30	0.39
Hip extensors	0.37	0.15	0.007*	0.24	0.34	0.05	0.23	0.34	0.06	0.24	0.35	0.06
Hip Abductors	0.45	0.22	0.001*	0.39	0.43	0.001*	0.39	0.43	0.002*	0.39	0.43	0.003*
Hip adductors	-0.11	0.01	0.41	-0.18	0.32	0.12	-0.18	0.33	0.10	-0.18	0.33	0.13
Knee flexors	0.53	0.18	0.003*	0.46	0.41	0.004*	0.45	0.41	0.004*	0.47	0.42	0.003*
Knee extensors	0.26	0.14	0.01*	0.26	0.41	0.003*	0.25	0.41	0.004*	0.25	0.42	0.005*
TUG (s)												
Hip flexors	-5.21	0.06	0.08	-4.02	0.25	0.15	-3.46	0.26	0.23	-3.27	0.28	0.25
Hip extensors	-6.22	0.14	0.008*	-4.54	0.28	0.04*	-4.31	0.30	0.05	-4.48	0.32	0.04*
Hip Abductors	-6.15	0.13	0.01*	-4.84	0.29	0.03*	-4.49	0.30	0.05	-4.34	0.31	0.06
Hip adductors	2.95	0.03	0.20	4.00	0.28	0.54	4.21	0.31	0.04*	3.94	0.32	0.06
Knee flexors	-7.92	0.13	0.01*	-7.48	0.33	0.009*	-7.39	0.35	0.009*	-7.71	0.38	0.006*
Knee extensors	-5.32	0.20	0.001*	-5.09	0.39	0.001*	-4.94	0.40	0.001*	-4.81	0.41	0.002*
5TSS (s)												
Hip flexors	-5.06	0.06	0.09	-4.05	0.20	0.15	-4.00	0.20	0.18	-3.97	0.20	0.19
Hip extensors	-5.21	0.10	0.02*	-3.75	0.21	0.10	-3.68	0.21	0.11	-3,74	0.21	0.11
Hip Abductors	-2.19	0.01	0.36	-0.91	0.16	0.69	-0.69	0.16	0.78	-0.65	0.17	0.79
Hip adductors	2.00	0.01	0.38	2.89	0.19	0.17	2.98	0.20	0.17	2.97	0.20	0.18
Knee flexors	-1.86	0.008	0.55	-1.20	0.16	0.69	-1.17	0.17	0.70	-1.24	0.17	0.68
Knee extensors	-4.84	0.17	0.004*	-4.65	0.31	0.004*	-4.64	0.31	0.004*	-4.65	0.31	0.005*

* $p < 0.05$
Adjustment 1: age and height; Adjustment 2: adjustment 1 + number of falls; Adjustment 3: adjustment 2 + number of vertebral fractures
Abbreviations: 5TSS = five times sit to stand; 5MWT = five metre walk test; TUG = Timed up and go

extensors (p = 0.03) and knee extensors (p = 0.004). For each 1 $Nmkg^{-1}$ increase in peak torque of hip extensors and knee extensors, 5TSS performance time reduced respectively by 5.2 s and 4.8 s.

Adjustment for age, height, number of falls and number of fractures in the regression model showed that the result of the 5TSS test explained 31% of the variance in peak strength of the knee extensors (p = 0.005). For each 1 $Nmkg^{-1}$ increase in peak torque 5TSS performance time decreased by 4.7 s.

Discussion

To the best of our knowledge, this is the first study to show that women with low bone mass and VFF had lower physical performance and reduced lower limb muscle strength (measured with a dynamometer) than women without vertebral fracture, confirming our initial hypotheses. Additionally, lower limb muscle strength was associated with physical performance (evaluated with the 5MWT, TUG and 5TSS) in women with VFF, regardless of the characteristics of the vertebral fracture and other confounding variables. However, in contrast with our initial hypothesis, VFF was only associated with reduced strength of the hip abductor muscles when adjusted for the number of fractures and other confounding variables; it was not associated with physical performance, or with the strength of other lower limb muscles.

Tests of physical performance have been used in studies with older people with vertebral fractures, despite the lack of reference values and cutoff points for this population. A prospective cohort study of community-dwelling older Brazilians [34] found that a cutoff performance time of 12.5 s for the TUG test was predictive of falls in older Brazilians. Another recent prospective study [35], which investigated the association between TUG performance time and fracture risk in older women, showed that TUG time > 12 seconds was strongly associated with hip fracture, fragility fractures (spine, hip, forearm, and proximal humerus) and non-fragility fractures. Although these prospective studies were conducted in older people, none focused on older women with VFF. However, considering the lowest cutoff point, the VFF group (13.4 s) is at risk of falls and new fractures. Falls in older people can have serious consequences such as hip fractures and loss of mobility and independence, and the presence of VFF is a risk factor for new vertebral and non-vertebral fractures in the following years [36]. We therefore suggest that prevention and early rehabilitation of vertebral fractures should be a high priority.

Gait speed is an appropriate measure to assess and monitor the functional status and general health of the population: it is a predictor of functional disability, mortality, institutionalization, and cognitive problems [37]. A prospective study with a 15-year follow-up showed that low pre-fracture gait speed was strongly associated with the risk of mortality after fracture in older people [38]. There is no consensus in the literature regarding a cutoff point, and no studies have been conducted post-vertebral fracture. One study reported that speeds above 1.0 m/s are associated with a lower risk of adverse events and better survival in older people in the community [39]. In our study, mean gait speed of the women in the VFF group was 0.9 m/s, which may indicate a risk for negative health outcomes.

In addition to representing dynamic balance [40], the 5TSS provides an indication of lower limb muscle function [20], particularly strength and power. In a Brazilian study, a cutoff of ≥ 13 s was found to accurately identify 85% of women with sarcopenia [41]. Although in our study performance time was > 13 s in both groups, it was longer in the VFF group (15.31 s vs. 13.42 s).

It is known that a vertebral fracture, even small, can alter spinal biomechanics. Disc degeneration and bone loss increase the load on the adjacent vertebra, increasing the risk of a new vertebral fracture [42], which, in turn, increases the degree of thoracic kyphosis and back pain, culminating in a loss of quality of life, morbidity, and mortality [43]. Balance [44] and gait instability [6] may be affected if the fracture causes a forward-bent posture; the feeling of instability can result in poorer performance in clinical trials. In addition, to compensate for trunk flexion, individuals with hyperkyphosis flex the knees and tilt the pelvis posteriorly to bring the head and shoulders back [45]. However, our hypothesis that these posture alterations could alter the length-tension relationship of the muscles and culminate in a decrease in lower limb muscle strength was not confirmed, since VFF was only associated with reduced hip abductor strength.

Women with vertebral fractures have lower muscle mass and strength (assessed by handgrip strength) compared to women without fractures [14]. Therefore, as we expected, strength of the hip abductors, hip and knee flexors and extensors was lower in the VFF than the NF group. However, the multiple linear regression showed that regardless of the number of fractures and other covariates, VFFs were associated only with a reduction in peak hip abductor torque. Although we did not find a significant association between peak torque of the other muscle groups and vertebral fracture, perhaps due to the type of assessment, i.e., isometric contraction or the body positioning, this finding is still relevant: the hip abductors are important for postural control and function in older women, and mediolateral instability has been described as an important risk factor for falls in this population [18]. This may explain why many studies show that vertebral fracture is associated with an increased risk of hip fracture, regardless of bone mineral status [46].

Our results showed that the number of vertebral fractures is an important factor in the relationship between VF and physical function, since the correlations were no longer significant when the number of vertebral fractures was added as a confounding variable in the statistical model. The number and severity of vertebral fractures has been found to be independently associated with slower TUG performance and reduced gait speed in older women [16]. Corroborating these data, another study showed that severe vertebral fractures in older women were associated with lower gait speed and slower 5TSS performance time, whereas there was no association for only 1 fracture [17]. As 68% of the VFF group had 1 or 2 fractures, this may explain the lack of association between VFF and physical performance.

Finally, to explore the association between VFF, physical function and muscle strength, it is clinically relevant to determine whether muscle strength contributes to physical performance in women with vertebral fractures because such information would help the elaboration of physical exercise programs that are appropriate to the people's needs.

The multiple linear regression showed that for each 1 $Nmkg^{-1}$ increase in knee extensor strength, 5MWT increased by 0.3 m/s, TUG performance increased by 4.8 s, and the 5TSS by 4.65 seconds in the VFF group, even after adjusting for confounding variables. Therefore we suggest that increasing the strength of the knee extensors could improve performance on clinical tests, in addition to reducing the risk of falls, since weakness of the quadriceps is a risk factor for falls [47]. We also suggest that knee flexor strength should be evaluated in clinical practice, since a 1 $Nmkg^{-1}$ increase in peak flexor torque was strongly associated with performance on the physical tests, explaining a decrease of 7.71 seconds for TUG and an increase in mean velocity of 0.47 m/s in the 5MWT test.

Studies previously published by our group showed an association between hip abductor strength and physical function in community-dwelling older adults: peak hip abductor torque contributed to static and dynamic balance, which was assessed by means of the single-leg stance and tandem gait test [18, 19]. Considering the fact that walking involves periods of single-leg support, it is understandable that hip abductor strength was associated with 5MWT in this study: a 1 $Nmkg^{-1}$ increase in hip abductor torque explained 0.39 m/s improvement in gait speed.

This study has several limitations. The measurement of strength only involved isometric contractions performed on an isokinetic dynamometer, however we chose this method because such contractions are safe in the older population. The study was a cross-sectional; therefore, we cannot make inferences about causality. Longitudinal studies are needed to investigate the cause-and-effect relationship. Finally, the convenience sample was composed of women with low bone mass, with no group of women with normal bone mass and without fractures.

The apparently small amount of variance explained (between 30 and 50%) may be due to the fact that physical function is multifactorial and does not only depend on muscle strength. In addition, older women have multisystem physiological changes that can influence the clinical outcome. Thus, future studies should evaluate different populations, and include more biomechanical factors to inform the rehabilitation of individuals with vertebral fractures.

The results of this study are clinically relevant since the variables measured can be modified through interventions that aim to maintain the independence of women with vertebral fractures for as long as possible. High-intensity muscle strength training stimulates the osteogenic response and preserves the quality of bone tissue [48]. According to the updated Cochrane review, there is only moderate evidence to support the use of physical exercise to improve physical function after vertebral fracture [49]: only 9 studies were included with small sample sizes, resulting in inaccurate estimates. Furthermore, only 1 trial included resistance exercise for lower limbs. We suggest that the results of the present study indicate that lower limb strength and power training programs could improve physical performance in older women with VFF. Therefore, randomized controlled trials evaluating interventions to improve physical performance should consider adding strength and power training programs for the lower limbs.

Author Contributions

Melise Jacon Peres-Ueno: data analysis, data tabulation, discussion of results, paper editing. Luana Leticia Capato: data analysis, data tabulation, discussion of results. Jaqueline Mello Porto: data analysis, data tabulation, discussion of results. Isabela Ferreira Adão: data analysis and data tabulation. Carlos Fernando Pereira da Silva Herrero: X-ray analysis, fragility fracture diagnosis and discussion of results. Marcello Henrique Nogueira-Barbosa: DEXA analysis, fragility fracture diagnosis and discussion of results. Eduardo Ferrioli: DEXA analysis and discussion of results. Francisco Jose Albuquerque de Paula: DEXA analysis and discussion of results. Daniela de Abreu: Guidance and monitoring of all experimental steps, data analysis, data tabulation, discussion of results, paper editing. Previous Interactions.

Data Availability

Data will be made available on request.

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.

Acknowledgments

The authors thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP – 2012/01770-1) for the research support. We also thank Abilio Borghi for English language assistance.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.rehab.2022.101680.

References

[1] Ziebart C, et al. Are osteoporotic vertebral fractures or forward head posture associated with performance-based measures of balance and mobility? Arch Osteoporos 2019;14(1):67.
[2] van der Jagt-Willems HC, et al. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC Geriatr 2015;15:34.
[3] Tosteson AN, et al. Impact of hip and vertebral fractures on quality-adjusted life years. Osteoporos Int 2001;12(12):1042–9.
[4] Melton LJ, et al. Vertebral fractures predict subsequent fractures. Osteoporos Int 1999;10(3):214–21.
[5] Lynn SG, Sinaki M, Westerlind KC. Balance characteristics of persons with osteoporosis. Arch Phys Med Rehabil 1997;78(3):273–7.
[6] de Groot MH, et al. A flexed posture in elderly patients is associated with impairments in postural control during walking. Gait Posture 2014;39(2):767–72.
[7] Cortet B, et al. Evaluation of spinal curvatures after a recent osteoporotic vertebral fracture. Joint Bone Spine 2002;69(2):201–8.
[8] Hall SE, et al. A case-control study of quality of life and functional impairment in women with long-standing vertebral osteoporotic fracture. Osteoporos Int 1999;9(6):508–15.
[9] Johnell O, Kanis JA. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int 2006;17(12):1726–33.
[10] Lindsay R, et al. Risk of new vertebral fracture in the year following a fracture. JAMA 2001;285(3):320–3.
[11] Agostini F, et al. Rehabilitative Good Practices in the Treatment of Sarcopenia: a Narrative Review. Am J Phys Med Rehabil 2021;100(3):280–7.
[12] Curtis E, et al. Determinants of muscle and bone aging. J Cell Physiol 2015;230 (11):2618–25.
[13] Herrmann M, et al. Interactions between muscle and bone-where physics meets biology. Biomolecules 2020;10(3).
[14] Eguchi Y, et al. Reduced leg muscle mass and lower grip strength in women are associated with osteoporotic vertebral compression fractures. Arch Osteoporos 2019;14(1):112.
[15] Hida T, et al. Sarcopenia and sarcopenic leg as potential risk factors for acute osteoporotic vertebral fracture among older women. Eur Spine J 2016;25(11):3424–31.
[16] Johansson L, et al. Vertebral fractures and their association with health-related quality of life, back pain and physical function in older women. Osteoporos Int 2018;29(1):89–99.
[17] Arima K, et al. Association of vertebral compression fractures with physical performance measures among community-dwelling Japanese women aged 40 years and older. BMC Musculoskelet Disord 2017;18(1):176.
[18] Porto JM, et al. Contribution of hip abductor-adductor muscles on static and dynamic balance of community-dwelling older adults. Aging Clin Exp Res 2019;31(5):621–7.
[19] Porto JM, et al. Diagnostic accuracy of clinical tests for the indirect assessment of hip abductor muscle strength in community-dwelling older women. Phys Ther 2020;100(11):1967–76.
[20] Goldberg A, et al. The five-times-sit-to-stand test: validity, reliability and detectable change in older females. Aging Clin Exp Res 2012;24(4):339–44.
[21] Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39(2):142–8.
[22] Porto JM, et al. Risk factors for future falls among community-dwelling older adults without a fall in the previous year: A prospective one-year longitudinal study. Arch Gerontol Geriatr 2020;91:104161.
[23] Morita M, et al. Relationship between falls and physical performance measures among community-dwelling elderly women in Japan. Aging Clin Exp Res 2005;17 (3):211–6.
[24] Vandenbroucke JP, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med 2007;4(10): e297.
[25] Matsudo S, et al., Questionário Internacional de Atividade Física (IPAQ): estudo de validade e reprodutibilidade no Brasil. 2001: Revista Brasileira de Atividade Física e Saúde. p. 5-18.
[26] Cangussu-Oliveira LM, et al. Association between the trunk muscle function performance and the presence of vertebral fracture in older women with low bone mass. Aging Clin Exp Res 2020;32(6):1067–76.
[27] Genant HK, et al. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res 1993;8(9):1137–48.
[28] Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. Ann Intern Med 2007;147(5):330–8.
[29] Johnson ME, et al. Age-related changes in hip abductor and adductor joint torques. Arch Phys Med Rehabil 2004;85(4):593–7.
[30] LaRoche DP, et al. Rapid torque development in older female fallers and nonfallers: a comparison across lower-extremity muscles. J Electromyogr Kinesiol 2010;20(3):482–8.
[31] Maffiuletti NA, et al. Rate of force development: physiological and methodological considerations. Eur J Appl Physiol 2016;116(6):1091–116.

[32] Arnold CM, et al. The reliability and validity of handheld dynamometry for the measurement of lower-extremity muscle strength in older adults. J Strength Cond Res 2010;24(3):815–24.
[33] Porto JM, et al. Relationship between grip strength and global muscle strength in community-dwelling older people. Arch Gerontol Geriatr 2019;82:273–8.
[34] Alexandre TS, et al. Accuracy of Timed Up and Go Test for screening risk of falls among community-dwelling elderly. Rev Bras Fisioter 2012;16(5):381–8.
[35] Larsson BAM, et al. The timed up and go test predicts fracture risk in older women independently of clinical risk factors and bone mineral density. Osteoporos Int 2021;32(1):75–84.
[36] Johnell O, et al. Fracture risk following an osteoporotic fracture. Osteoporos Int 2004;15(3):175–9.
[37] Middleton A, Fritz SL, Lusardi M. Walking speed: the functional vital sign. J Aging Phys Act 2015;23(2):314–22.
[38] Koivunen K, et al. Mortality risk among older people who did versus did not sustain a fracture: baseline prefracture strength and gait speed as predictors in a 15-Year Follow-Up. J Gerontol A Biol Sci Med Sci 2020;75(10):1996–2002.
[39] Abellan van Kan G, et al. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. J Nutr Health Aging 2009;13(10):881–9.
[40] Ward RE, et al. Functional performance as a predictor of injurious falls in older adults. J Am Geriatr Soc 2015;63(2):315–20.
[41] Pinheiro PA, et al. Chair Stand Test" as simple tool for sarcopenia screening in elderly women. J Nutr Health Aging 2016;20(1):56–9.
[42] Broy SB. The Vertebral Fracture Cascade: Etiology and Clinical Implications. J Clin Densitom 2016;19(1):29–34.
[43] Nuti R, et al. Undiagnosed vertebral fractures influence quality of life in postmenopausal women with reduced ultrasound parameters. Clin Orthop Relat Res 2014;472(7):2254–61.
[44] Sinaki M, et al. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporos Int 2005;16(8):1004–10.
[45] Yuan HA, Brown CW, Phillips FM. Osteoporotic spinal deformity: a biomechanical rationale for the clinical consequences and treatment of vertebral body compression fractures. J Spinal Disord Tech 2004;17 (3):236–42.
[46] Black DM, et al. Prevalent vertebral deformities predict hip fractures and new vertebral deformities but not wrist fractures. Study of Osteoporotic Fractures Research Group. J Bone Miner Res 1999;14(5):821–8.
[47] Hakestad KA, et al. Exercises including weight vests and a patient education program for women with osteopenia: a feasibility study of the OsteoACTIVE rehabilitation program. J Orthop Sports Phys Ther 2015;45 (2):97–105 C1-4.
[48] Beck BR, et al. Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis. J Sci Med Sport 2017;20(5):438–45.
[49] Gibbs JC, et al. Exercise for improving outcomes after osteoporotic vertebral fracture. Cochrane Database Syst Rev 2019;7:CD008618.