



Are osteoporotic vertebral fractures or forward head posture associated with performance-based measures of balance and mobility?

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Abstract

Summary The main objective of this study was to explore whether vertebral fracture characteristics or posture is independently associated with physical performance. Posture was significantly associated with physical performance but fracture characteristics were not, suggesting posture should be the focus of physical performance variance.

Purpose The main objective of this study was to explore whether vertebral fracture characteristics (number, severity, location) or occiput-to-wall distance (OWD) is independently associated with physical performance.

Methods This was a secondary data analysis using baseline data from a randomized controlled trial, of community-dwelling women aged 65 years and older with a suspected vertebral fragility fracture. Lateral thoracic and lumbar spine radiographs were used to determine the number, location, and severity of fracture. The dependent variables were timed up and go (TUG), five times sit-to-stand, four-meter walk, and step test. The independent variables were number, severity, location of fracture, and OWD. Pain during movement and age were covariates. Multivariable regression analyses determined the association between each of the dependent and independent variables.

Results Participants' ($n = 158$) mean (standard deviation [SD]) age was 75.9 (6.5) years. They had a mean (SD) BMI, OWD, and number of fractures of 26.7 (5.3) kg/m², 5.7 (4.6) cm, and 2.2 (1.8), respectively. OWD was independently associated with TUG (estimated coefficient [B] = 0.29, 95% confidence interval [CI] = 0.16, 0.42), five times sit-to-stand ($B = 0.33$, 95% CI = 0.12, 0.55), four-meter walk ($B = 0.09$, 95% CI = 0.05, 0.13), and step test ($B = -0.36$, 95% CI = -0.50, -0.23) in the unadjusted model. OWD was independently associated with TUG ($B = 0.25$, 95% CI = 0.12, 0.38), five times sit-to-stand ($B = 0.29$, 95% CI = 0.07, 0.50), four-meter walk ($B = 0.08$, 95% CI = 0.03, 0.12), and step test ($B = -0.22$, 95% CI = -0.47, -0.19) in the adjusted model.

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Conclusion OWD was significantly associated with physical performance but fracture characteristics were not. These analyses were exploratory and require replication in future studies.

Keywords Hyperkyphosis · Vertebral fractures · Osteoporosis · Occiput-to-wall distance · Older adults · Physical performance

Introduction

Vertebral fragility fractures are the most common osteoporotic fracture [1]. The risk of sustaining a vertebral fracture increases with age. The prevalence of vertebral fractures in women aged 50–59 is 5–10%, but it increases to greater than 30% in women over 80 years of age [2]. The risk of future fracture doubles [3, 4] in the year after the initial vertebral fracture [5]. Vertebral fractures lead to further consequences such as back pain [3], reduced physical activity, balance impairments [6], impaired gait [7], height loss [8], and postural changes [9].

The number, severity, and location of vertebral fractures have been associated with head posture, as measured by occiput-to-wall distance (OWD) [10–12]. Increased severity of fracture (as measured by the Genant fracture assessment) [13] and number of fractures have been shown to increase OWD [10]. As well, the location of fracture seems to contribute to OWD, such that thoracic vertebral fractures are significantly associated with an increase in hyperkyphosis, which is defined as an increase in the natural thoracic curvature of the spine, and may contribute to postural changes [9]. Individuals with thoracic vertebral fractures had a greater kyphotic angle and OWD than those without thoracic vertebral fractures [13].

Both vertebral fractures and hyperkyphosis have been associated with back pain [11], poor physical function [12], muscle weakness [12], and fear of falling [14], which may contribute to impaired physical performance in individuals with osteoporotic vertebral fractures. Hyperkyphosis has been reported to be an independent risk factor for falls [15], due to a forward shift in the center of mass and center of pressure decreasing stability [7]. It has been proposed that, to counter forward flexion, individuals with hyperkyphosis would create a counterbalance by flexing the knees and tilting the pelvis posteriorly, to bring the head and shoulders back [7]. Example strategies to improve stability during walking include shorter stride length, slower gait velocity, and slower cadence, which create irregular trunk acceleration, decreased static, and dynamic balance [1], and exacerbate instability and fall risk. Incidence of vertebral fractures increases with age [2], and vertebral fractures can result in acute and chronic pain [11]. Individuals in pain adopt forward flexed postures [7], which may contribute further to changes in gait and balance. To date, no studies have explored the independent contributions of number, severity, location of fractures, forward head posture, or pain to physical performance. Understanding if posture contributes to physical performance variability independent

of vertebral fracture characteristics would provide support the use of postural interventions among individuals with osteoporotic vertebral fractures, in addition to other pharmacological and non-pharmacological strategies to reduce future fracture risk.

Therefore, the main objective of this study was to explore whether vertebral fracture characteristics, particularly number, severity, location, or OWD, are independently associated with physical performance in a variety of physical performance measures including timed up and go, five times sit-to-stand, four-meter walk, and step test.

Methods

Study design

This exploratory cross-sectional study was a secondary analysis of baseline data from the Build Better Bones with Exercise (B3E) trial. B3E was a one-year, multi-site (seven sites: St. Mary's Hospital-University of Waterloo, McMaster University, University of Toronto/Toronto General Hospital, Western University/St. Joseph's Health Care, University of British Columbia, Broadmeadows Health Service in Australia, and Royal Melbourne Hospital/University of Melbourne in Australia), randomized controlled trial of thrice-weekly home exercise compared with control (equal attention) in women aged 65 years or older with at least one, radiographically confirmed, vertebral fracture. [16]. The study protocol has been published (NCT01761084) [16]. For the current study, we used data from participants screened for the inclusion in the B3E randomized control trial.

Outcome measures

We used occiput-to-wall distance (OWD) (cm) to measure forward head posture, a proxy measure for hyperkyphosis [1]. OWD is measured by having the participant stand with their heels and hips flat against a wall. The evaluator measures the distance from the occiput to the wall. OWD has a high correlation ($r = 0.902$, $p < 0.001$) with the Flexicurve measure of kyphosis, indicating strong concurrent validity [17]. The sensitivity and specificity of OWD to detect prevalent thoracic fractures encountered in the clinical practice were 41% and 92%, respectively, and an OWD greater than 5 cm is indicative of hyperkyphosis [18]. OWD has strong inter-rater reliability [19].

All participants had lateral thoracic and lumbar spine radiographs in a hospital or clinic by an X-ray technician, unless the participant had a recent (within six months) X-ray as part of usual clinical care. A single musculoskeletal radiologist examined all radiographs to identify the number, location (from T4–L5), and the severity of vertebral fracture(s). Participants were not screened for other potentially confounding spine disorders like scoliosis and ankylosing spondylitis. The radiologist reviewing the X-rays was a musculoskeletal radiologist with fellowship training and 17 years of experience.

Fracture severity

The severity of the fracture was categorized based on the Genant vertebral fracture classification [20], which has a three-point scale classification (grade 1, grade 2, and grade 3). We classified only grade 2 (25–40% compressed) and grade 3 (greater than 40% compressed) fractures as morphometric fractures [21], as we were concerned about the accuracy and reliability of classifying grade 1 fractures (20–25% compressed) [21]. Fracture severity was considered a categorical variable, such that participants were grouped into one of the three categories: grade 0–1 fracture(s), one or more grade 2 fracture(s), or at least one grade 3 fracture. Therefore, individuals with multiple fractures of different severity would be grouped into the highest severity category, regardless of the number of fractures.

Fracture location

We created three fracture location variables based on three regions of the spine: fractures occurring in the mid-thoracic region (T4–8), fractures occurring between the thoracolumbar junction (T9–L1), and in the lumbar region (L2–L5). This was determined based on clinical relevance and previous studies identifying fractures occurring within these locations [8, 9]. If an individual had a fracture in the location, it was coded with a 1 and if there was no fracture in the location it was coded with a zero. For example, a participant with a fracture at T8, T9, and L1 was coded: T4–T8 = 1, T9–L1 = 1, L2–L5 = 0. The location variable was binary, not categorical. This was done to try to avoid addressing the number and location of fractures in the same variable.

Number of fractures

The number of fractures was determined as the number of prevalent grade 2 or 3 fractures for each participant.

Physical assessments

Four physical performance assessments were selected as measures of functional mobility, lower extremity strength and

power, and dynamic balance. The timed up and go (TUG) test was selected as a measure of functional mobility, dynamic balance, and obstacle avoidance (by walking around a cone), which have been shown to decrease in individuals with increased postural sway and decreased leg muscle strength [22]. The TUG has shown excellent test-retest reliability [23], inter/intra-rater reliability [24]. The test measures the time it takes for an individual to stand up from a chair, walk three meters, walk back, and sit down in the chair again. A chair of 45-cm height and armrest height of 65 cm was used. A line was marked on the floor three meters from the chair. The participant was instructed to wear their usual footwear. The participant starts with their back against the chair, using their arms resting on the armrests and could use a walking aid if they chose. The participant was instructed to stand up, walk at their usual pace to the line on the floor, turn, return to the chair, and sit down again. The time began when the research assistant told the participant to “go”. If the test was not completed the first time, the test could be repeated. The time is recorded in seconds for the first attempt if it was successfully completed. If a second attempt was required, the time for attempt one and two should be recorded in seconds.

The five times sit-to-stand was selected as a measure of functional lower extremity power and strength [25], with adequate test-retest reliability [26] and adequate construct validity [27]. The participant was initially instructed to perform a single chair stand test to determine the safety of performing the five times sit-to-stand. The participant was seated in a stable chair, 45-cm high and 47.5-cm deep, with a straight back and a solid seat. The participant was asked to stand up from the chair with their arms folded across their chest and feet on the floor. If the participant could not stand without using their arms, they did not perform the five times sit-to-stand. If it was safe to try the five times sit-to-stand, the participant was told to stand up straight as quickly as possible five times, without stopping in between. The participant was asked to keep their arms folded across their chest. The participant was timed from the initial sitting position to the final standing position, at the end of the fifth stand, to see how quickly they could perform five times sit-to-stand. The test was stopped if the participant used their arms or did not completely rise from the chair in 1 min or if there was a concern for the participant’s safety.

The four-meter walk test was selected as a measure of mobility [28], with adequate inter-rater reliability [29] and adequate validity [29]. The step test was selected as an assessment of dynamic balance. A four-meter straight walking path was marked using tape on the floor. A 1-m distance both before and after the four-meter walking path was marked, to minimize the effect of acceleration and deceleration. The participant could use a walking aid if they chose. The test was timed beginning when the first foot crossed the leading edge of the piece of tape that constituted the 4-m line. The timer was

stopped when the foot crossed the end of the four-meter marked path. The participant was instructed to walk the distance twice (there and back), and the fastest time was recorded.

Step test has not been validated in patients with osteoporosis but has shown excellent test-retest reliability [30] and inter/intra-rater reliability [31]. The step test is the most challenging balance test of the physical performance assessments in B3E due to the dynamic movement on a single leg stance, while further requiring muscle strength to clear the step [30]. The participant stood unsupported with their shoes removed, feet parallel and 10 cm apart with a block 5 cm directly in front of them. The participant was advised to step with one leg at a time. The participant was instructed to place the whole foot on the block and then to return it fully back down to the floor repeatedly as fast as possible for 15 s. One complete step comprises placing the foot fully up onto then down off the block. The number of steps was recorded. If the participant lost their balance during the test, the number of steps was recorded up to that point and the test was stopped. After the number of steps for one foot was completed, the same procedure was done for the other foot. The number of steps completed in 15 s is recorded for each foot individually; an average number of steps were used in the analysis.

Potential confounding variables that were considered for inclusion in the regression models were age and pain. Pain and age have been shown to contribute to both vertebral fractures and OWD [32]. Pain was assessed using a visual analogue scale (VAS), which asked participants to rate their pain during movement, in the past week, on a scale from 0 to 10, with zero being no pain at all and 10 being unbearable pain. Age was self-reported.

Statistical analysis

All analyses were performed with SPSS version 23 for Windows (IBM SPSS statistics, Armonk, NY). Descriptive statistics, such as age (years), body mass index (kg/m^2), height (cm), weight (kg), occiput-to-wall distance (cm), number of fractures, each physical performance measure, number of medications and supplements, and number of comorbidities, were reported as mean and standard deviation. The frequencies of location and severity of vertebral fractures were presented as counts and percentages.

The main objective was to determine the association between vertebral fracture characteristics (number, severity, and location), posture (OWD), and the four physical performance measures (timed up and go, five times sit-to-stand, four-meter walk Test, and step test). Multivariable linear regression analyses were performed with fracture characteristics and OWD as independent variables. Each physical performance test was a dependent variable. A model for the unadjusted and adjusted for age and pain during movement was generated. No

variables were removed based on p values as previous work suggests that when determining an association between variables, removing variables based on significance adds bias [33]. In the final models, a p value of < 0.05 was considered statistically significant. Due to the exploratory nature of this study, all variables of interest were forced into the model to gain insight into the associations of the independent variables with the dependent variable. All requisite assumptions were tested.

Results

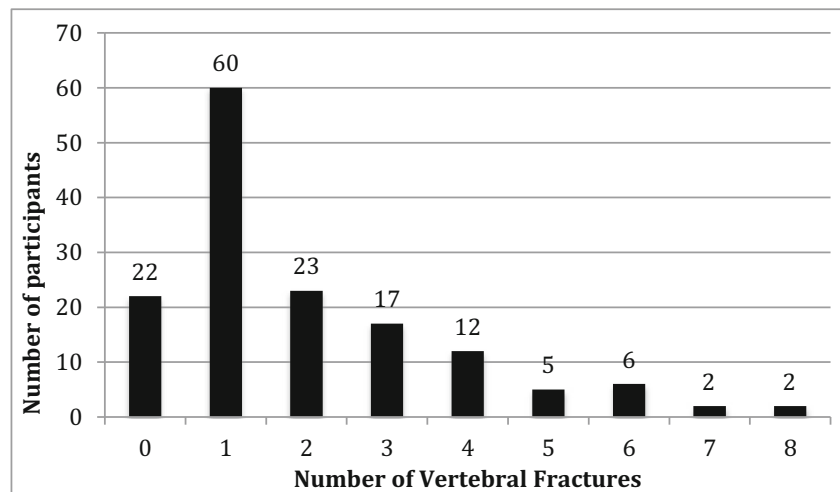
A total of 181 participants were screened and underwent an X-ray, and 22 (12%) were excluded or withdrew consent and were not included in the current analysis. One participant attended the baseline visit but chose to not participate in the physical performance measures, because she felt unsafe performing the tasks, and was therefore excluded from the analyses. The current analyses were completed using data from 158 participants. The mean (standard deviation) age of the participants was 76 (6.5) years, with a BMI of 26.7 (7.1) kg/m^2 (Table 1). On average, participants had 2.2 (1.8) fractures (Fig. 1), with 142 of the participants having a grade 2 or higher fractures. Most of the fractures were in the grade 3 severity category ($n = 95$) and in the T9–L1 location ($n = 107$) (Table 1; Fig. 2). The participants had, on average, 2.5 (2.4) comorbidities and were taking 5.3 (4) medications and

Table 1. Descriptive participant information

	<i>N</i>	Mean	Stdv
Age (years)	158	75.9	6.5
Height (cm)	158	156.4	7.1
Weight (kg)	158	65.4	14.1
BMI	158	26.7	5.3
OWD (cm)	158	5.7	4.6
Fracture number	158	2.2	1.8
Number of comorbidities	158	2.5	2.4
Number of medications/supplements	158	5.3	3.9
Number of fractures	158	2.2	1.8
No. fractures (<i>n</i>)	13		
Severity of fractures (<i>N</i>)	158		
Grade 0–1 (<i>n</i>)	16		
Grade 2 (<i>n</i>)	47		
Grade 3 (<i>n</i>)	95		
Location of fractures (<i>N</i>)	158		
T1–T3	4		
T4–T8 (<i>n</i>)	65		
T9–L1 (<i>n</i>)	107		
L2–L5 (<i>n</i>)	57		

OWD, occiput-to-wall Distance; BMI, body mass index

Fig. 1 Frequency of fractures, representing the number of participants with the number of fracture ranging from 0 to 8 fractures



supplements (Table 1). The average OWD was 5.7 cm (Fig. 3). The mean time for the TUG test was 11.9 (3.9) seconds. For participants that reported using a gait aid, the mean TUG time was 17.93 s (5.1, $n = 30$), which is above the 13.5 s cutoff score for fall risk (Table 2).

Timed up and go test

In the unadjusted multivariable regression, 15% of the variance in the TUG was explained by the independent variables ($p < 0.001$). OWD was the only variable that was significantly associated with TUG ($p < 0.001$). For every centimeter increase in OWD, TUG time increased by 0.29 s (Table 3). None of the fracture variables were associated with TUG in the unadjusted regression ($p > 0.05$).

The adjusted multivariable regression model, for the TUG test, was statistically significant ($p < 0.001$) and accounted for 20% of the variability in TUG. OWD and pain during movement were independently associated with TUG. For every

centimeter increase in OWD, TUG time increased by 0.25 s. Age and fracture characteristics were not associated with TUG performance (Table 3).

Five times sit-to-stand test

In the unadjusted multivariable regression model, 13% of the variance in the five times sit-to-stand was explained by the independent variables ($p < 0.001$). OWD was the only variable that was significantly associated with five times sit-to-stand ($p < 0.001$). For every centimeter increase in OWD, five times sit-to-stand time increased by 0.33 s (Table 3).

In the adjusted multivariable regression model, 16% of the variance was explained when age and pain during movement were included in the model. OWD was the only variable that was independently associated ($p < 0.01$) with five times sit-to-stand performance. For every centimeter increase in OWD, five times sit-to-stand test increased by 0.29 s. Although L2–L5 was not statistically significant, the magnitude of the association is large, such that for every fracture in L2–L5, five times sit-to-stand time increased by 2.84 s (Table 3).

Four-meter walk test

The unadjusted multivariable regression model was statistically significant and accounted for 18% of the variability in the four-meter walk test. OWD and fracture severity were statistically significant at $p < 0.001$ and $p = 0.03$, respectively (Table 3).

The adjusted multivariable regression model was statistically significant, accounting for 24% of the variability in the four-meter walk test ($p < 0.001$). OWD ($p < 0.001$) and fracture severity ($p < 0.01$) were significantly associated with the four-meter walk test when accounting for pain and age in the model (Table 3).

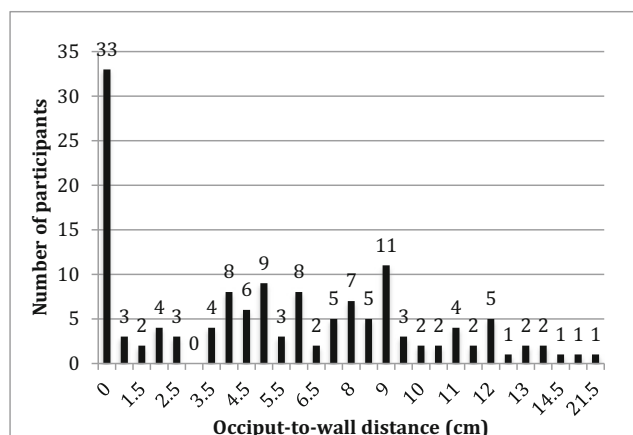
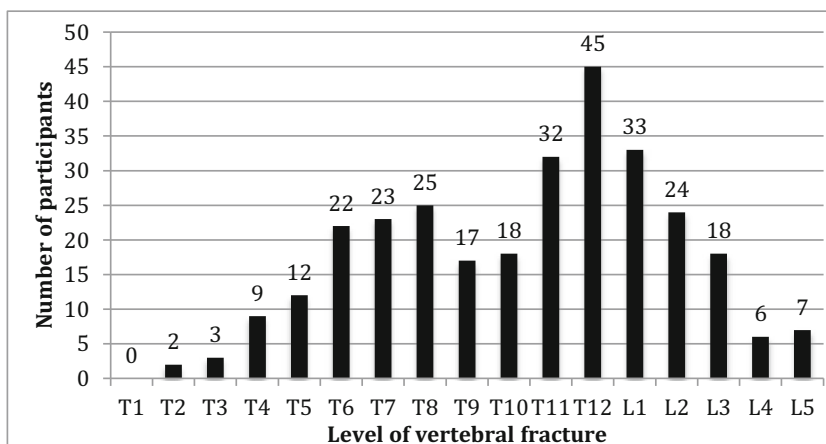


Fig. 2 Frequency of fractures by location of vertebral fracture, representing the number of participants with a fracture in each location from T1–L5

Fig. 3 Frequency of occiput-to-wall distance, representing the number of participants with the distance from their occiput bone to the wall ranging from 0 to 21.5 cm



Step test

The unadjusted multivariable regression model was statistically significant and accounted for 18% of the variability in the step test. OWD was the only variable that was statistically significant in the unadjusted model ($p < 0.001$), such that for every centimeter increase in OWD, the number of steps decreased by 0.36 (Table 3).

Adjusting for age and pain during movement in the regression model accounted for 21% of the variance in the step test ($p < 0.001$). OWD and pain during movement were statistically significant explanatory variables, such that for every centimeter increase in OWD, the number of steps decreased by 0.38, and for every grade category increase in fracture severity, step test number decreased by 0.29 steps (Table 3).

Discussion

Our exploratory analyses suggest that OWD explains a greater proportion of variance in physical performance than do fracture characteristics in older women with a suspected vertebral fracture, particularly for the TUG and four-meter walk tests. It is unclear from the current study whether the poor physical performance was a cause or consequence of increased forward flexed posture. The associations between OWD, fracture characteristics, and physical performance measures were weak,

suggesting that other factors beyond fracture characteristics and posture contribute to physical performance variability, such as osteoarthritis or neurological disorders. We also noted that the presence of pain during movement may be an important variable to consider when assessing physical performance in women with a suspected vertebral fracture.

Individuals with vertebral fractures may limit their physical activity to attempt to reduce pain [34]. Individuals with lumbar fractures report more severe pain, partially due to the weight-bearing nature of the lumbar vertebrae and the increased moments, shear, and compression forces around those vertebrae [35]. The lumbar vertebrae have a high threshold and slow conduction velocity mechanosensitive afferent units, which may serve as nociceptors in the lumbar facet joints, resulting in low back pain [36]. Pain during movement was significantly associated with performance on the TUG, four-meter walk, step test, and approached statistical significance in the five times sit-to-stand, suggesting that pain may need to be addressed when designing interventions to improve physical performance.

Greater OWD or hyperkyphosis is independently associated with mobility impairments (e.g., slower TUG and four-meter walk time) [1, 7, 37]. Katzman et al. (2011) demonstrated that hyperkyphosis significantly contributed to TUG performance [38], such that per every standard deviation increase in kyphosis angle, TUG time increased by 0.11 s. We demonstrated that for every standard deviation increase in OWD, TUG time increased by 0.32 s. The average TUG time was

Table 2 Descriptive statistics of physical performance assessments comparing all participants, those that reported not using a gait during daily living and those that reported using a gait aid during daily living

	All participants			No gait aid			Gait aid		
	<i>n</i>	Mean	Stdv	<i>n</i>	Mean	Stdv	<i>n</i>	Mean	Stdv
Five times sit-to-stand (s)	137	15.3	5.8	101	14.4	5.8	35	17.9	5.1
Imputed five times sit-to-stand (s)	158	15.6	6.4	108	14.3	5.6	49	18.7	6.8
Four-meter walk (s)	158	4.2	1.3	108	3.8	0.9	49	5.2	1.4
Step test (number of steps)	158	11.8	4.2	108	13.0	3.8	48	9.5	3.3
Timed up and go (s)	158	11.9	4.0	108	10.6	2.8	49	15.2	4.0

Table 3. Unadjusted variance in Time Up and Go, five times sit-to-stand test, four-meter walk test, step test, and Timed Loaded Standing test, multivariable regression

	Unadjusted			Adjusted*		
	Beta coefficient	95% confidence interval	<i>p</i> value	Beta coefficient	95% confidence interval	<i>p</i> value
Timed up and go						
Number of fracture	-0.04	(-0.68, 0.60)	0.9	-0.09	(-0.72, 0.54)	0.79
Severity of fracture	0.27	(-0.59, 1.14)	0.53	0.53	(-0.34, 1.41)	0.23
T4-T8	-0.19	(-2.03, 1.64)	0.83	-0.15	(-1.95, 1.65)	0.87
T9-L1	0.06	(-1.93, 2.06)	0.95	-0.08	(-2.03, 1.87)	0.94
L2-L5	0.64	(-1.22, 2.50)	0.5	0.52	(-1.30, 2.34)	0.58
OWD	0.29	(0.16, 0.42)	<0.001	0.25	(0.12, 0.38)	<0.001
<i>R</i> ²			0.15			0.23
Five times sit-to-stand						
Number of fracture	-0.11	(-1.16, 0.95)	0.84	-0.18	(-1.22, 0.86)	0.73
Severity of fracture	-0.11	(-1.52, 1.31)	0.88	0.34	(-1.10, 1.78)	0.64
T4-T8	-1.58	(-4.60, 1.44)	0.3	-1.48	(-4.45, 1.49)	0.36
T9-L1	0.66	(-2.61, 3.94)	0.69	0.62	(-2.60, 3.85)	0.7
L2-L5	2.93	(-0.12, 5.98)	0.06	2.84	(-0.16, 5.84)	0.06
OWD	0.33	(0.12, 0.55)	0.002	0.29	(0.07, 0.50)	0.01
<i>R</i> ²			0.13			0.16
Four-meter walk test						
Number of fracture	0.14	(-0.06, 0.34)	0.18	0.12	(0.43, 4.88)	0.23
Severity of fracture	0.3	(0.03, 0.57)	0.03	0.37	(0.10, 0.64)	0.01
T4-T8	-0.49	(-1.07, 0.08)	0.09	-0.48	(-1.05, 0.08)	0.09
T9-L1	-0.46	(-1.09, 0.16)	0.14	-0.51	(-1.12, 0.10)	0.1
L2-L5	-0.36	(-0.94, 0.22)	0.22	-0.41	(-0.98, 0.16)	0.16
OWD	0.09	(0.05, 0.13)	<0.001	0.08	(0.03, 0.12)	<0.001
<i>R</i> ²			0.18			0.24
Step test						
Number of fracture	0.1	(-0.56, 0.76)	0.77	0.15	(-0.51, 0.80)	0.66
Severity of fracture	0.41	(-0.48, 1.30)	0.36	0.28	(-0.63, 1.12)	0.54
T4-T8	0	(-1.89, 1.90)	>0.99	0	(-1.87, 1.87)	>0.99
T9-L1	-0.95	(-3.00, 1.10)	0.36	-0.82	(-2.91, -1.29)	0.43
L2-L5	-0.56	(-2.47, 1.35)	0.57	-0.42	(-2.31, 1.47)	0.66
OWD	-0.36	(-0.50, -0.23)	<0.001	-0.33	(-0.47, -0.19)	<0.001
<i>R</i> ²			0.18			0.21

*The adjusted multivariable analysis was accounted for age and pain during movement as confounding variables

11.9 s, and a TUG time of 10 s is a suggested cutoff score indicating risk of falls for individuals with hip osteoarthritis [39], and therefore, 30% of our sample would be classified as at risk of falling using this time cutoff score. Hyperkyphosis may result in balance impairments from a forward flexed posture [1, 6, 37] and gait unsteadiness from an increase in gait variability [7]. In our study, OWD explained more variance in four-meter walk test than other variables known to influence mobility including pain, age, and vertebral fractures. Individuals with osteoporosis and hyperkyphosis typically have slower gait and shorter stride length [37], increasing fall

risk. However, 52 participants reported using a gait aid during their daily activities, but only 11 participants used gait aid during the TUG test. Individuals with more variable gait patterns are more cautious [40], contributing to a slower performance time on the TUG and four-meter walk tests.

A sense of instability may result in worse performance on assessments involving lower extremity strength, such as the five times sit-to-stand or the TUG, which was observed in the current study. Individuals with osteoporosis and hyperkyphosis have been shown to have decreased lower extremity strength [6, 12, 37]. Lower extremity strength is

associated with an impaired ability to control the center of mass within the base of support, resulting in more mediolateral displacement and greater mediolateral velocity [37]. Individuals with osteoporosis and hyperkyphosis typically demonstrate reduced hip abductor strength, knee extensor strength, ankle dorsiflexion, grip strength [37], and quadriceps strength [41] compared with controls without osteoporosis or hyperkyphosis. OWD was independently associated with five times sit-to-stand performance in both the unadjusted and adjusted models in our study, suggesting that performance variability is linked to lower extremity strength.

Dynamic balance may be impaired in the presence of hyperkyphosis in women with osteoporosis because the center of mass is closer to the edge of the limits of stability. In our study, OWD was shown to modestly contribute to the step test performance, a measure of dynamic balance. A score of less than 10 steps is considered clinically relevant [42], and the average number of steps in our sample was 11.8, but with every standard deviation increase in OWD, the number of steps performed decreased by 0.4, suggesting that an increase in OWD can clinically decrease the ability to perform step test. Older adults have a diminished ability to transfer weight from one leg to the other due to a disruption in the timing of forces being generated and the rate of change [40]. Furthermore, studies by Lynn et al. [6] and Jonsson [40] exhibited that older adults may unload too soon with respect to displacement of the center of mass (COM), leading to more postural adjustments in order to be able to control the COM. In contrast, younger adults demonstrate a longer unloading phase and larger temporal delay between the attainment of the maximal vertical and lateral forces [6, 40]. Thus, it is not surprising that OWD was associated with dynamic balance assessments in our study.

Fracture characteristics were either not associated or modestly associated with physical performance, which is in contrast with findings from previous studies [4, 43]. Discrepant findings may be due to a different grading system for fractures [4] or did not account for posture [43]. For example, the risk of poor performance in the chair stand and walking test was found to increase with an increasing number of fracture (OR = 1.60) [4, 43]. Exercise interventions targeting posture have been shown to improve posture, and our study suggests that we should explore their efficacy for improving physical performance [44].

There were several limitations to this study. Firstly, this was an exploratory nature and therefore the conclusions should be interpreted with caution. Future studies should confirm the findings with larger sample size. The use of OWD to assess hyperkyphosis may not be sensitive enough to detect subtle posture changes; however, OWD represents a cheaper and less burdensome measure of posture for use in a clinical setting. This study was cross-sectional in nature and therefore cannot provide inferences on causality. Future work should examine longitudinal relationships between posture and physical performance in individuals with vertebral fractures. Further, there is

strong evidence to suggest that balance is impaired in individuals with hyperkyphosis [13]; however, static balance was not assessed in isolation in this study. The results cannot be generalized to men, and the women in this study may be more physically impaired or present with greater OWD than women without a suspected vertebral fracture. Number, severity, and location were used, in this study, to categorize vertebral fractures; however, whether the anterior, middle, or posterior portion of the vertebral body was compressed was not taken into account.

Conclusion

OWD was significantly associated with each of the physical performance tests measured in this study of older women with suspected vertebral fractures. OWD was statistically significantly associated with TUG, five times sit-to-stand, four-meter walk, and step test, whereas vertebral fracture characteristics were not. Number and severity of fractures were associated with physical performance, in particular, the four-meter walk test, but only explained a modest amount of variance. Future analyses should continue to study the effect with larger sample size.

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Compliance with ethical standards

Conflict of interest None.

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