The Association between Fractures, Posture and Physical Performance Measures in Women Over the Age of 65

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Background Information: Vertebral fractures are a common type of osteoporotic fracture, associated with increased morbidity and mortality. An accumulation of vertebral fractures may lead to postural changes including hyperkyphosis. However, hyperkyphosis may also be caused from habitual forward flexion and weakening of the back extensor muscles. The associations between vertebral fractures, posture and physical performance remain unclear.

Objectives: Our primary objective was to investigate the association between number, severity, and location of vertebral fractures (vertebral fracture characteristics), or posture (OWD) and performance on the Timed Up and Go (TUG) test. Secondary objectives were to understand the association between vertebral fracture characteristics or OWD and other physical performance measures; and between vertebral fracture characteristics and OWD.

Methods: We used baseline data from a multi-site randomized controlled trial of women over the age of 65 with a suspected vertebral fragility fracture. SPSS was used to run multivariable regression models to evaluate relationships between variables for each objective. A p-value of <0.05 was considered statistically significant. Both adjusted and unadjusted models were generated, where the adjusted model accounted for age, and pain.

Results: A total of 158 women were included in the study. The mean age (SD), BMI (SD), OWD (SD), and number of fractures was 75.9 (6.5) years, 26.7 (5.3) kg/m^2, 5.7 (4.6) cm, and 2.5 (2.4), respectively. OWD (B=0.25 95% CI= 0.12,0.38) and pain (B=0.32 95% CI=0.10,0.53) were independently associated with TUG, four-meter walk (OWD: B=0.08 95% CI=0.03,0.12; pain: B=0.11 95% CI=0.04,0.18), and step test (OWD: B= -0.33 95% CI=-0.47,-0.19; pain: B= -0.29 95% CI=-0.51,-0.07). OWD was independently associated with five times sit-to-stand (B=0.29 95% CI=0.07,0.50). Severity of fracture was independently associated with four-meter walk test. Number of fractures (B=0.82 95% CI=0.04-1.59) and pain (B=0.30 95% CI=0.04,0.56) were independently associated with OWD.

Conclusion: OWD was significantly associated with each of the physical performance tests, and contributed more to physical performance variability than number, severity and location of fracture.

Keywords: hyperkyphosis, vertebral fractures, osteoporosis, occiput-to-wall distance, older adults, physical performance

Lay Summary:

Spine fractures are a common problem in people with osteoporosis, leading to posture changes. It’s unclear whether the spine fractures or posture changes, or both affect physical performance. We found that posture was related to physical performance, more so than number, severity and location of fracture.

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Chapter 1

Introduction

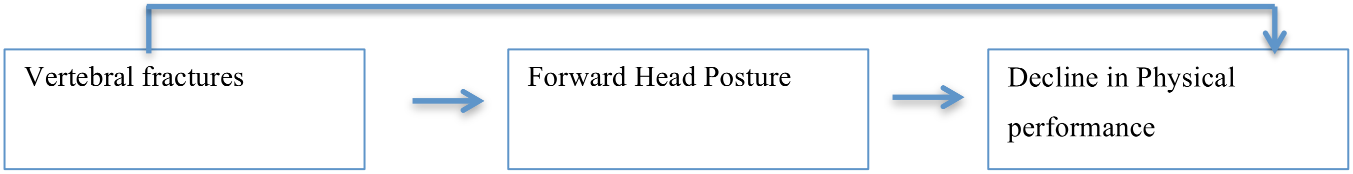

Figure 1: Overall conceptual framework driving the thesis

Osteoporosis is a metabolic bone disease, characterized by low bone strength, deterioration of bone tissue, and an increased risk of fractures[1]. An osteoporotic fracture is more common than a heart attack, stroke and breast cancer combined[2]. At least one in three women, and one in five men will suffer from an osteoporotic fracture during their lifetime[2]. Specifically, osteoporosis accounts for 80% of fractures in adults aged 50 years and older and has been associated with increased morbidity and mortality[2]. Osteoporotic fractures are commonly termed fragility fractures. Fragility fractures occur spontaneously or due to a low trauma incident, such as from a fall from standing height or less[3]. The cost of fragility fractures in Canada was $2.3 billion in 2010, and is expected to rise[4]. Osteoporotic fragility fractures commonly occur at the hip, wrist, and spine[5]. Vertebral fragility fractures are the most common sub-type of fragility fracture and are associated with postural changes, and impaired physical performance, which is the basis for the development of the conceptual framework guiding this thesis.

Figure 1 highlights the overall conceptual framework of this thesis. Ultimately it is hypothesize that vertebral fractures will contribute to postural changes, like forward head posture, which will consequently contribute to declines in physical performance. However, it is also possible, that vertebral fractures are independently contributing to declines in physical performance (without postural changes acting as mediator). This thesis has two primary components: determining the association between vertebral fractures and forward head postures, and secondly, determining the associations between forward head posture and physical performance.

Vertebral fractures are defined as a collapse of the vertebrae, by at least 20%. A fracture will occur when the bone strength is less than that of the applied load. As individuals age, bone resorption increases relative to bone formation[6,7], resulting in a net loss of bone mineral density. Trabecular bone is resorbed earlier and is more noticeably than cortical bone. Specifically there is a decrease in trabecular number and connectivity, resulting in overall loss in bone mineral density. Vertebrae are largely composed of trabecular bone, explaining the high likelihood of vertebral fractures[6,7]. Compression, torsional and shear loads are the most common types of loads that cause vertebral fractures. It is common for individuals to fracture vertebrae from lifting heavy objectives due to increases in the compressive loads at the spine[8]. Torsional loads occur in a twisting motion and increase the risk of fracture because of the decrease in trabeculae[9]. Individuals with osteoporosis often fracture from torsional forces like getting out of bed, sudden rotational movements, or a fall[8]. Shear loads are attenuated by horizontally oriented trabeculae[9], which would distribute the forces from bending over, a fall, and daily activities that involve forward flexion. Therefore, bending, falling and daily activities are a common etiology for vertebral fractures[8], in individuals with compromised bone mineral density. However, nearly half of vertebral fracture occur spontaneously and are often asymptomatic[10], and as such, the etiology of vertebral fractures is not clearly understood.

Vertebral fractures have been associated with a number of physical consequences. Individuals with

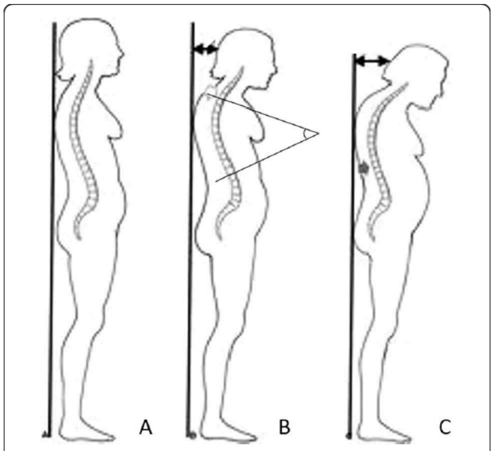

Figure 2: Adapted from van der Jagt-Willems (2015) showing A) a woman without postural changes B) a woman with a hyperkyphotic curve as measured by occiput-to-wall distance and C) a women with an increased hyeprkyphotic curve, which increases FHP

vertebral fractures often report back pain[8], reduced physical activity, balance impairments[11], impaired gait[12], and posture changes[13]. Physical consequences associated with vertebral fractures may be explained by vertebral fracture characteristics. Biomechanical factors from variations in the curvature of the spine are thought to contribute to non-uniform risk of fracture. The mid-thoracic region and thoracolumbar spine regions are the most likely to fracture due to the highly kyphotic curve at the thoracic spine, and the shift from kyphotic to lordotic curve at the thoracolumbar junction, resulting in high loads transmitted to those regions[14]. In individuals with mid thoracic fractures, back extensor muscles weaken, resulting in an increase in the natural kyphotic curve in the thoracic spine and in severe cases, hyperkyphosis[15].

Hyperkyphosis is defined as an exaggerated kyphotic curve in the thoracic spine, and is typically measured radiographically. However, radiographic images can be burdensome on the participants and are more costly than a proxy measure for hyperkyphosis, like forward head posture (FHP). FHP has been associated with hyperkyphosis, such that an increased hyperkyphotic curve increases FHP (Figure 2).

Hyperkyphosis often occurs in the presence of vertebral fractures. An increase in the number of vertebral fractures results in greater anterior translation of the trunk, increasing hyperkyphosis, which increases the amount of load on the anterior portion of the vertebrae from the upper body. But, since the strength of the vertebrae is already compromised, the vertebrae cannot withstand the additional forces from the upper body and consequently fracture; which further increases the loading on the anterior portion of adjacent vertebrae and the cascade continues.

Hyperkyphosis and vertebral fractures have been associated with impaired muscle control[11], poor balance[16], muscle weakness[16], pain[10] and fear of falling[17], which are factors known to influence physical function. However, not all individuals with vertebral fractures have hyperkyphosis, and not all individuals with hyperkyphosis have vertebral fractures. It may be the number, severity or location of fracture that influences postural changes after a vertebral fracture. Few studies have examined the association between vertebral fractures, characteristics of vertebral fractures and hyperkyphosis on physical performance variability in older adults. No studies have looked at the association between fracture characteristics such as number, severity and location of fractures, posture (forward head posture), and diverse physical performance outcomes reflective of mobility, lower leg strength and dynamic balance, in women with a suspected vertebral fracture.

An analysis of whether vertebral fractures or forward head posture lead more to physical performance variability would provide insight into how to target interventions towards improving physical performance and falls prevention. For example, if forward head posture contributes more to performance variability then interventions should target posture re-training. The primary research question is: do fracture characteristics or forward head posture explain more variance in physical performance measures in women with a suspected vertebral fracture, over the age of 65? It is hypothesized that forward head posture will contribute more to physical performance variability than vertebral fracture characteristics.

Chapter 2

Literature Review

2.1 Overview

Osteoporosis can be defined as a bone disease, characterized by low bone strength, deterioration of bone tissue leading to increased bone frailty and a consequent increased risk for fracture[1]. Fracture risk factors include: age, female gender, prior fragility fracture, fractures at the hip or spine, current smoking, oral glucocorticoid use, more than three alcoholic drinks per day, rheumatoid arthritis, secondary osteoporosis or their bone mineral density falls within the osteoporosis range (T-score of -2.5 or less), and with increasing age[18]. Fractures occur when the applied load is greater than bone strength. In individuals with osteoporosis, their bone strength is compromised such that the applied load doesn't have to be very large to cause a fracture. It is not uncommon for individuals with osteoporosis to fracture from a fall, by bending over, or during activities of daily living. The most common types of osteoporotic fractures are at the hip, wrist, shoulder and vertebrae. Vertebral fragility fractures are among the most common sub-type of fragility fractures in individuals with osteoporosis[19,20].

2.2 Vertebral fractures overview

Vertebral fragility fractures are the most common osteoporotic fracture[19,20]. Vertebral fractures account for an estimated 700,000 of the 1.5 million osteoporotic fractures in the United States[21]. The risk of sustaining a vertebral fracture increases with age. The prevalence of vertebral fractures in women aged 50-59 is 5-10%, but increases to greater than 30% in women over 80 years of age[2]. Females with vertebral fractures have a doubled risk of hip fracture and approximately four times greater risk for a new vertebral fracture[8,22]. Nineteen per cent of women with a new vertebral fracture have an incident vertebral fracture in the next year [23].

The vertebral column is complex, made up of many articulating vertebrae. The spinal column is made up of twenty-four individual articulating vertebrae, separated by intervertebral discs[24]. The articulating vertebrae can be further divided into three components: the cervical, thoracic and lumbar spine. The cervical spine is made up of seven vertebrae, oriented with a slight concavity[25]. The thoracic spine is made up of twelve vertebrae, forming a kyphotic curve[25]. The lumbar spine has five vertebrae, oriented with a concave, lordotic curve[24]. The natural curves of the spine slightly modify the loading characteristics within each section, increasing the risk of fracture in certain areas of the spine.

The number, severity and location of the fracture are primarily used to characterize vertebral fractures. The number of vertebrae that have some degree of compression quantifies number of fracture. The degree of compression refers to the severity of the fracture. Genant's fracture grading system is a well-received semi-quantitative (based on visual inspection) strategy to quantify the severity of vertebral fractures[26]. Typically vertebrae from T4-L4 are assessed and then categorized into a grade 1 fracture, which is approximately 20-25% reduction in anterior, middle and/or posterior

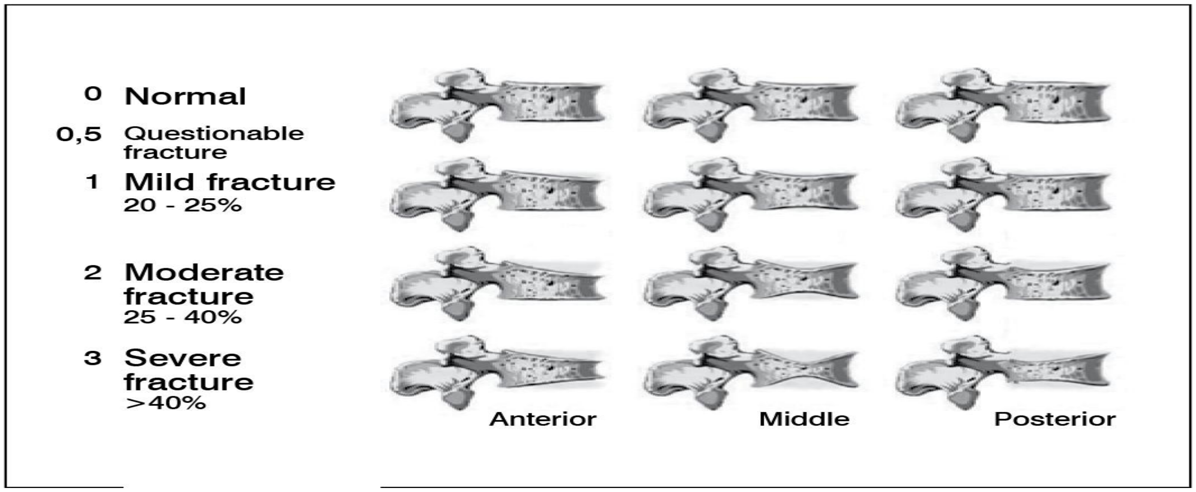

Figure 3: Figure adapted from Genant fracture grading system[26], depicting the grade of fracture based on percent compression in the anterior, middle and posterior section of a single vertebra

height, a grade 2 fracture, which is approximately 25-40% reduction of any height, and grade 3 fracture, which is reduction of greater than 40% of any height[26] (Figure 3). The location of fracture describes which vertebrae are fractured.

A vertebral fracture is defined as a collapse of the vertebra[26]. Vertebral fragility fractures involve the vertebral body and include some combination of compression (collapse of the entire vertebral body), concavity (collapse of the vertebral endplates), or wedging (relative loss of anterior height) [27]. Generally, vertebrae are less dense anteriorly and superiorly, and denser posteriorly and inferiorly[28-31], reducing the loading capabilities of the anterior portion of the vertebrae. Due to the reduced density of the anterior portion of the vertebra, anterior wedge fractures are among the most common type of vertebral fracture[28-31], which is a reduction in height of the anterior portion of the vertebrae. An accumulation of anterior wedge fractures can change the loading characteristics at the vertebrae, which increases the applied load on the vertebrae further increasing fracture risk.

The risk of a sustaining a vertebral fracture is a function of the loading conditions and the ability of the spine to withstand the load[32]. Compression, torsional and shear loads are the types of loads that cause fractures. Vertebral compressive strength is determined mostly by vertebral size, specifically the amount of trabecular bone within the vertebrae[9]. Since trabecular bone is resorbed more evidently and earlier than cortical bone, the risk of compressive fractures increases[32]. It is common for individuals to fracture vertebrae from lifting heavy objectives because it increases the compressive loads at the spine[8]. Torsional loads occur in a twisting motion and increase the risk of fracture because the force loads the spine disproportionately increasing the loads on one component of the vertebrae. Since there is a decrease in vertically and horizontally oriented trabeculae in individuals with osteoporosis torsional loads increase the risk of fracturing[9]. Individuals with osteoporosis often fracture from torsional loads like getting out of bed, sudden rotational movements, or a fall[8]. Shear loads are attenuated by horizontally oriented trabeculae[9], which would distribute the forces from bending over, a fall, and daily activities that involve forward flexion. Therefore, bending, falling and daily activities are a common etiology for vertebral fractures[8]. However, it's been suggested that nearly half of vertebral fracture occur spontaneously[10], so the etiology of many vertebral fractures is not clearly understood.

Vertebral fractures have been associated with a number of physical consequences. Individuals with vertebral fractures often report back pain[8], reduced physical activity, balance impairments[11], impaired gait[12], and posture changes[13]. Physical consequences associated with vertebral fractures may be associated with vertebral fracture characteristics. Fractures occur more often in the mid-thoracic region (T7-T8), and the thoracolumbar region (T11-L1) more than other regions in the spine[33,34]. It has been suggested that biomechanical factors from variations in the curvature of the spine cause the non-uniform risk of fracturing. The largest thoracic kyphosis occurs around T7-T8 resulting in larger anterior bending moments and increased risk of anterior wedge fractures[14,35], from increased compressive and shear forces about those vertebrae[14]. At the thoracolumbar junction, the spine transitions from a kyphotic to a lordotic curve, and no longer has the support of the rib cage, causing more spinal mobility, increasing fracture risk. The mechanisms underlying the increased prevalence of thoracolumbar fractures are not completely understood[35]. The combination of changing loading characteristics about the spine after a vertebral fracture, and the high prevalence of fractures in the thoracic and thoracolumbar regions, can result in postural changes like hyperkyphosis suggesting that hyperkyphosis is a potential cause and consequence of vertebral fractures. What remains unclear is whether the physical impairments associated with vertebral fracture are due to the fractures themselves, or whether postural changes like hyperkyphosis contributes more to impaired physical functioning in individuals with osteoporosis.

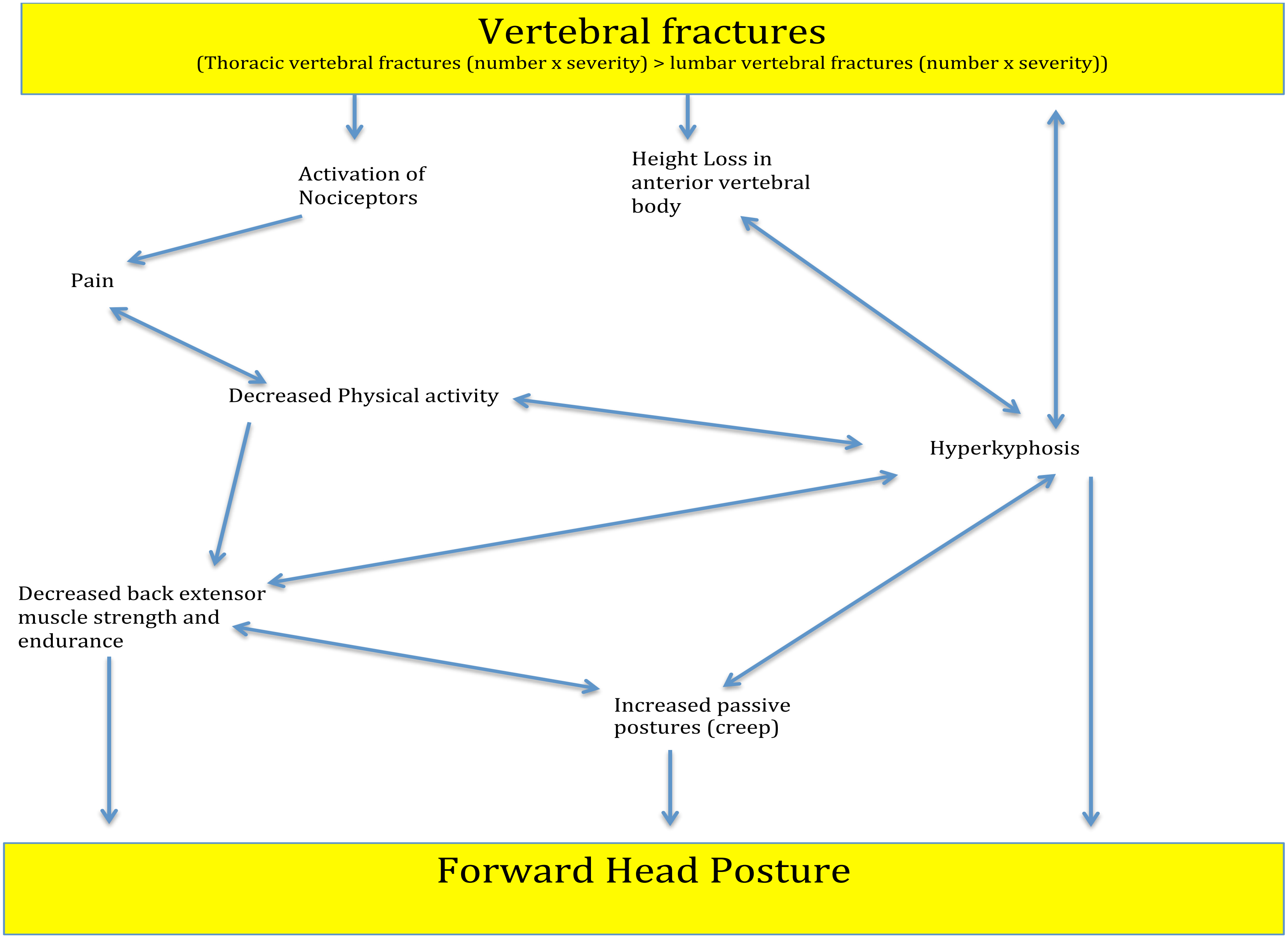

Figure 4: Conceptual framework of the associations between vertebral fractures and forward head posture. The framework shows potential confounding variables for the potential relationship between vertebral fractures and forward head posture, but there may also be a direct relationship between vertebral fracture characteristics and forward head posture. The top banner represents the hypothesis that there is an interaction between number and severity, and that thoracic contributes more than lumbar.

2.3 Hyperkyphosis overview

Hyperkyphosis is defined as an increase in the normal thoracic curvature of the spine[36]. Hyperkyphosis is typically measured by calculating the kyphotic angle using a radiograph image, however, instruments like the flexicurve, Debrunner kyphometer, and occiput-to-wall distance have also been used as valid, reliable and cheaper methods of measuring hyperkyphosis[13].But hyperkyphosis can be difficult to measure and burdensome to the participant and economically. A proxy measure of hyperkyphosis that is less burdensome is forward head posture (FHP), as measured by occiput-to-wall distance[19]. FHP measures the distance from the participant's occiput bone on the back of the head, to the wall, while the participant is standing with their heels, hips and shoulders against he wall and their chin parallel to the ground[19].

2.4 Association between vertebral fractures and FHP

Hyperkyphosis may contribute to the cause of vertebral fractures. Decreased physical activity from vertebral fractures, which can lead to pain, hyperkyphosis, and a fear of falling can further increase risk of fractures by decreasing back extensor endurance, decrease overall muscle strength, increase passive postures and increase loading on the spine[37-40] (Figure 4).

Pain is associated with vertebral fractures[10] and may contribute to the development of hyperkyphosis and forward head posture. Acute pain has been used in the diagnosis of an incident vertebral fracture, with pain being one of the first clinical markers of a vertebral fracture[41]. In a large prospective study, it was found that individuals with incident vertebral fractures had a 2.4 greater odd of experiencing back pain. Incident fractures also increased the odds of back disability (as assessed by doing exercising involving the back) by 2.6, and at least one day of bed rest by 7.9[42]. Therefore the contribution of pain to forward head posture is likely through multiple mechanisms including decreased back extensor muscle strength and endurance, leading to hyperkyphosis which can lead to forward head posture. As well, through decreased physical activity leading to decreased back muscle strength and endurance, leading to hyperkyphosis and forward head posture. Or, through an accumulation of vertebral fractures which can lead to hyperkyphosis and forward head posture.

An accumulation of vertebral fractures has been associated with hyperkyphosis, suggesting that hyperkyphosis is a consequence of vertebral fractures. The vertebral fracture cascade has been used to explain that fracture risk increases exponentially after multiple fractures[32], because the loading characteristics around the fractured vertebrae change. With more anterior wedge fractures, there is greater anterior translation of the trunk, increasing hyperkyphosis, which increases the amount of load on the anterior portion of the vertebrae from the upper body[32]. But, since the strength of the vertebrae is already compromised because of more bone resportion than formation, the vertebrae are not strong enough to withstand the additional forces from the upper body and consequently fracture; which further increases the loading on the anterior portion of adjacent vertebrae and the cascade continues[35]. Anterior wedge deformities may be a result of reduced muscle activation[43], increasing hyperkyphosis, causing an increase in anterior loading of the vertebrae.

Back extensor muscle weakness is likely the underlying mechanism causing vertebral fractures from hyperkyphosis[15]. Hyperkyphosis increases the length of intrafusal fibres within the paraspinal muscles, diminishing position sense of the spine[44,45]. Individuals with hyperkyphosis have difficulty recognizing abnormal movement and correcting their kyphosis to achieve a neutral spine[46,47]. As back extensor muscles weaken, there is an anterior displacement of the trunk, reducing the ability of the back extensor muscles to resist shear forces[32]. Over-activation of the back extensors will increase compressive forces at the spine, putting the individual at a higher risk of future fracture[32]. However, the over-activation of back extensor muscles leads to earlier onset fatigue[14], further increasing hyperkyphosis, increasing loading on the anterior portion of the spine. It is thought that this constant forward posture from a decrease in back extensor muscle endurance contributes to increased forward head posture.

Alternatively, soft tissue creep could explain the increased stooped posture in individuals with hyperkyphosis. Creep in the spinal extensor muscles is a deformation of the muscles after undergoing a constant load over time[48]. There is an expulsion of water from the spinal tissues resulting in a loss of height and slack in the posterior ligaments[43] and can occur in the spine after sustained[48,49], or repetitive[48] flexion. Creep can cause a reduced resistance to bending[50], increasing the risk of fracturing for individuals with osteoporosis. It was noted that the onset of creep is much quicker in the thoracic spine, than in the lumbar spine[43], explaining the potential of creep to contribute to hyperkyphosis, supporting the idea that hyperkyphosis may also cause fractures. However, not all individuals that have vertebral fractures have hyperkyphosis[11,51]. Vertebral fracture characteristics (location, number and severity of compression) may provide insight into why some individuals experience hyperkyphosis and others do not.

The location of the vertebral fracture may contribute to whether hyperkyphosis develops. Thoracic vertebral fractures are significantly associated with an increase in hyperkyphosis, more than fractures located in the thoracolumbar junction or lumbar vertebrae[13]. Thoracic vertebral fractures have been shown to contribute more to FHP than fractures in other locations. Individuals with thoracic vertebral fractures had a greater kyphotic angle and occiput-to-wall distance (OWD) than those without thoracic vertebral fractures[52]. The odds of having a thoracic vertebral fracture increased by 3.3° for each standard deviation increase in OWD, and each additional thoracic vertebral fracture led to a 3.7° increase in kyphotic angle[52]. It would be expected that an increased number of fractures would occur at the thoracolumbar junction, as this is the pivot point of the spine moving from the thoracic kyphosis to lumbar lordotic curves, it is the position in the spine that has the least amount of physiological support from bones and muscles, and an increase in thoracic kyphosis leads to an increase in compressive forces at the thoracolumbar junction, due to an increased moment arm around those vertebrae[32], thus, increasing the number of fractured vertebrae in the thoracolumbar region.

However, FHP is likely influenced by thoracic vertebral fractures, since this location will increase the kyphotic curve of the thoracic spine, increasing FHP. Further research is required to understand which location, or whether another fracture characteristic contributes more to increased FHP.

Changes in posture as a result of vertebral fractures may be due to an increased number of prevalent vertebral fractures. The vertebral fracture cascade suggests that fracture risk increases exponentially after a single fracture[8], and that posture changes may result from an accumulation of vertebral fractures. One study noted that hyperkyphosis, as determined through radiographic images, increases with increasing number of fracture. However, another study looked at the relationship between number of fractures and OWD, and found no significant relationship[53]. It could be that OWD is not as sensitive of a posture measure as radiographic measures of hyperkyphosis, and therefore cannot detect subtle changes in posture that occur due to an increased number of fractures. It is also feasible the number of fractures is not the primary fracture characteristic contributing to FHP and that location or severity may contribute more.

The severity of a fracture has been associated with posture changes. Individuals with severe vertebral deformities commonly sustain more severe incident vertebral fractures, with fracture severity predicting the risk of future vertebral fracture[8,54,55]. OWD increased significantly with an increasing severity of fracture[52]. Individuals with a grade 1, grade 2 and grade 3 fracture had an average OWD of 2.3 cm, 4.3 cm and 8.1 cm, respectively[52]. It was also found that an increased severity of prevalent vertebral fractures increases the risk of sustaining a new vertebral fracture, compared to individuals with mild severity incident fractures or no vertebral fracture[54], suggesting that severity of fracture may be related to increased risk of future fracture.

What remains unclear is which fracture characteristic is most related to the development of hyperkyphosis. While there is evidence to suggest each of location, number and severity all contribute to hyperkyphosis, no studies have looked at all of these fracture characteristics. Insight into the association between fracture characteristics and hyperkyphosis is valuable to provide interventions to individuals before they develop hyperkyphosis. Preventing hyperkyphosis may be valuable to reduce the risk of future vertebral fracture. Further, as it is unclear how vertebral fractures and hyperkyphosis contribute to impaired physical function, it is unclear how fracture characteristics contribute to impaired physical function. Analyzing how fracture characteristics influence impaired physical function can further inform risk factors to impaired physical function in women with osteoporosis.

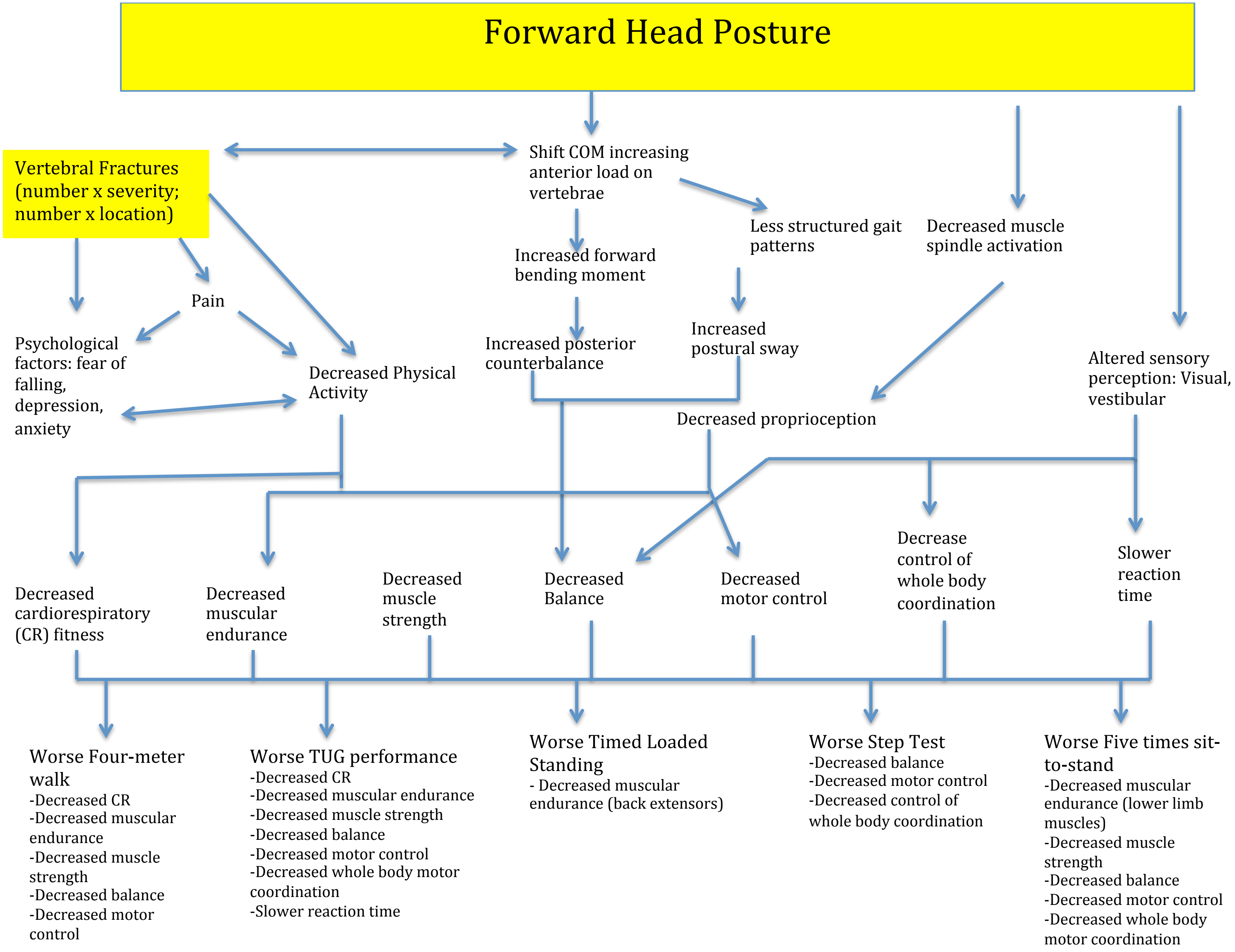

Figure 6: Conceptual framework of the associations between forward head posture and physical performance, highlighting the associations between forward head posture, vertebral fractures, and declines in physical performance, as well as potential confounding variables

2.5 Impairments in Physical Performance in Individuals with Vertebral Fractures and Forward Head Posture

Impaired physical performance is a consequence of both vertebral fractures and hyperkyphosis. Both vertebral fractures and hyperkyphosis have been associated with back pain[10], poor physical function[16], muscle weakness[16], and fear of falling[17], which may contribute to impaired physical performance. Hyperkyphosis has been reported to be an independent risk factor for falls[56]. The decreased BMD of individuals with osteoporosis cannot withstand the load of a fall, which will cause them to fracture. Underlying gait and balance impairments are likely the cause of increased risk of falls in individuals with hyperkyphosis.

A forward flexed posture leads to a shift in the center of mass and center of pressure, increasing the forward bending moment, decreasing stability[12]. To counter forward flexion, an increased posterior counterbalance is adapted through flexing the knees and titling the pelvis posteriorly, to bring the head and shoulders back [12]. As a result, older adults begin to rely more on a hip strategy for movement than an ankle strategy[11]. Increased reliance on a hip strategy results in increased instability, specifically when walking on uneven or slippery surfaces[11]. Older adults with osteoporosis and kyphosis demonstrated further reliance on the hip strategy [11,20], resulting in increased postural sway[11] during static balance. Due to the anterior displacement of the upper body, the center of mass shifts closer to the limits of the base of support, creating further instability[57]. The physical adaptations as a result of hyperkyphosis cause variable and less structured gait patterns (i.e., shorter stride length, slower gait velocity, wider step width, slower cadence), irregular trunk acceleration, decreased static and dynamic balance[19,20], which would affect performance on mobility and balance assessments, like the Timed Up and Go test (TUG), Five times sit-to-stand, Four-meter walk test, and Step test, which all include components of balance and lower limb muscle strength and endurance. However, physical impairments may not fully account for the declines in physical functioning in individuals with osteoporosis and forward head posture.

Postural control relies on the harmony between the visual, vestibular, and proprioceptive systems. The downward translation of the head in people with forward head posture may modify the signals from the visual and vestibular system, because their neck proprioception is altered, limiting the ability to adjust postural sway[58,59]. The greatest difference in sway velocity between women with osteoporosis and controls was noted on a stable surface with eyes open[60]. The ability to use vision to maintain balance is compromised in individuals with osteoporosis, likely due to the downward translation of the head from forward head posture. However, it's also been found that individuals with osteoporosis have conflicting sensory-motor inputs, which challenges the ability to identify the most relevant sensory information, potentially affecting motor control and reaction time, to create proper postural responses to balance perturbances[60]. It is hypothesized that forward head posture may decrease neck muscle spindle activation, which is influenced by chronic pain[61]. Muscle spindles are, in part, responsible for providing proprioceptive feedback[62], suggesting that forward head posture contributes to decreased proprioception. Decreased proprioception has been linked to decreased muscle endurance, balance[63] motor control[64]. Hyperkyphosis and forward head posture may also contribute to aerobic exercise limitations.

Psychological factors contribute, in part, to physical performance declines in individuals with hyperkyphosis, and vertebral fractures. Women with a fragility fracture reported less physical activity due to a fear of falling[65], and had worse performance on the chair stand test, balance tests, walking speed, tandem walking speed and step length, compared to those without fragility fractures[66]. Herman et al., (2005) noted that fear of falling and depression were significantly related to stride-to-stride variability (inability to maintain a stable walking pattern, and longer stride time) [67]. However, this was a cross-sectional study and therefore, it was unclear whether gait impairments lead to fear of falling or vice versa. Understanding this limitation, the group identified that a potential explanation may be due to dysrhythmicity, an instability in gait and an inability to maintain a steady walking rhythm, exacerbating a fear of falling and lack of self-confidence[67]. But, maintaining balance and postural control is more complex than psychological factors, and relies on the integration of multiple systems, as previously discussed.

An observed relationship between physical performance and fractures or posture may be confounded by pain. Severe pain has been associated with declines in gait velocity and balance[68]. As well, back pain, specifically, was significantly and inversely, associated with balance and functional mobility[69]. However, a review article noted that chronic back pain is often due to psychological factors such as low mood, anxiety, poor physical health, previous physical abuse and passive coping[70], but other factors such as pathologies, injuries, and reduced physical activity may also contribute. The review did not go into depth on the association between pain and physical performance and the relationship with vertebral fractures or posture, however, it would be hypothesized that pain would be increased in individuals with forward head posture, due to the etiology of forward head posture from vertebral fractures (which may activate nociceptors) and hyperkyphosis, which can also lead to pain. Future work examining the relationship between fractures, posture and physical performance should consider whether pain is a confounder or an effect modifier.

Older adults with a history of falling have greater gait unsteadiness than community-dwelling adults without a history of falls[71]. When observing the phases of gait, older adults with a history of falling have greater variability in any given phase than non-falling counterparts. There is diminished ability to maintain constant gait for older adults at risk of falling[71]. The risk of increased falls related to gait variability is a complex problem and has been suggested to be related to an increase in fatigue[71], increased time spent in gait phases[71], medication[72], fear of falling[67], and neuropsychological factors[73] such as attention, processing speed, and executive functioning. More specifically, imbalance and tripping over obstacles, during walking are two of the most common causes of falls in the elderly[74,75]. Older adults with osteoporosis have worse balance and gait during both obstructed and unobstructed walking[20]. It was suggested that this could potentially be due to decreased hip abductor strength, but could be due to posture changes leading to higher sway velocities[20], which may affect performance on the TUG test, due to the component of walking around an obstacle in the assessment. Individuals with osteoporosis present higher sway velocity and a greater number of falls compared to individuals without osteoporosis[20,60]. When asked to shift their center of pressure (COP) closer to their limits of stability, women with osteoporosis had higher sway amplitudes in the anterior-posterior direction[11,60]. Higher sway velocities may be due to an anterior shift in trunk mass from hyperkyphosis and forward head posture, displacing the center of gravity anteriorly, closer to the edge of the stability limits[60]. Although fall risk is increased from gait unsteadiness, it is not the only factor contributing to fall risk.

Overall, there are a few key gaps in the literature on the association between vertebral fractures, hyperkyphosis and physical performance. Firstly, although there is an association between vertebral fractures and hyperkyphosis, not all individuals that have a vertebral fracture develop hyperkyphosis. An analysis of vertebral fracture characteristics would provide insight into the factors most important to understand posture changes, and the associated decline in physical function. As well, what is unclear is which factor, vertebral fractures or forward head posture, contribute more to declining physical function in individuals with osteoporosis. These associations are important for understanding how to design interventions aimed towards reducing declining physical function.

2.6 Objectives and Hypotheses

The overall objective of this project was to explain the variance in physical performance in women with a suspected vertebral fracture over the age of 65 by exploring vertebral fracture characteristics and posture. I hypothesized that occiput-to-wall distance (OWD) will explain more of the variance in physical performance measures than will fracture characteristics. A summary of objectives, hypotheses and statistical analyses are presented in Table 1.

The first objective was to determine the association between vertebral fracture characteristics (number, severity and location) and OWD. It was hypothesized that thoracic vertebral fractures, greater number and more severe vertebral fractures would contribute to a greater OWD.

The second objective was to determine the association between vertebral fracture characteristics (number, severity, location), posture and the Timed up and Go test. It was hypothesized that a greater number, greater severity, more mid thoracic (T9-L1) vertebral fractures, and a greater OWD will result in worse performance on the TUG

The third objective was created to explore the associations between other physical performance assessments, FHP and vertebral fractures as there is very little research done on the associations between physical assessments, FHP and vertebral fracture characteristics (number, severity and location). The associations between FHP, number, severity and location of fractures and five times sit-to-stand, four-meter walk, step test and timed loaded standing were conducted as the third objective. It was hypothesized that a greater OWD will result in worse performance on the five times sit-to-stand, four-meter walk, step test and timed loaded standing.

Chapter 3
Methods

3.1 Study Design

A secondary analysis of baseline data from the Build Better Bones with Exercise (B3E) study was conducted for the current cross-sectional study. B3E is 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 control trial of thrice-weekly home exercise compared to control (equal attention) in women aged 65 years or older with a vertebral fracture,[76]. The study protocol can be found here: https://clinicaltrials.gov/ct2/show/NCT01761084?term=Build+Better+Bones+with+Exercise&rank=1 (NCT01761084). The home exercise group was prescribed activities to target strength, balance, aerobic, and posture training. Baseline assessments were completed from September 2013 to November 2015. A research assistant at each site obtained written informed consent, and performed assessments for all of the participants. B3E received ethics approval from each site, and the Office of Research Ethics at the University of Waterloo approved the protocol for this secondary analysis.

3.2 Participants

All participants that were screened for inclusion in the Build Better Bones with Exercise (B3E) study were considered for inclusion in the current secondary analysis. Participants were eligible for inclusion in B3E if they were female, ≥65 years of age and had a radiographic evidence of a non-traumatic fracture of one or more vertebrae between T1 and L4. Vertebral fractures were defined as radiographic presence of ≥ 25% reduction in anterior, middle or posterior height of a vertebra[77], which is considered a grade 2 fracture or greater, based off of the Genant fracture grading system[26]. If fracture history was uncertain, the presence of hyperkyphosis, documented height loss of >2cm or historical height loss of ≥ 6cm was criteria for sending for X-ray verification. In the current study, all participants with a completed baseline visit were included, including participants without a vertebral fracture, or without a Grade 2 vertebral fracture (≤25% height loss). Participants that did not have completed baseline data were not included in the current study. Additional exclusion criteria for B3E and the current study included: index vertebral fracture due to trauma; not able to communicate in English; on dialysis; palliative care; current/ prior cancer in the past 5 years (except basal cell carcinoma); clinically significant kidney, liver or intestinal disease; exercise participation ≥ 3 times per week that addresses ≥ two of five domains in the B3E exercise prescription; progressive neurological disorder, or progressive disorder likely to prevent study completion; unable to stand or walk for 10 meters with/ without gait aid; impaired capacity to give informed consent; or contraindication to exercise as determined by physician.

3.3 Medical History and Demographics

Past and current medication use, demographic, and lifestyle characteristics were obtained via interviewer-assisted questionnaire. Data were collected on vertebral fracture history, calcium and vitamin D supplementation, use of osteoporosis medication, number of months on osteoporosis medication, glucocorticoid use, and history of co-morbidities (e.g., rheumatoid arthritis, osteoarthritis, hypertension, cardiovascular disease, and diabetes).

3.4 Outcome Measures

Five times sit-to-stand, four-meter walk test, step test, timed up and go and timed loading standing tests were selected based on the tests' ability to measure the expected physical performance impairments in individuals with hyperkyphosis (Appendix 1). The five times sit-to-stand was selected as a measure of lower leg strength, lower leg power, dynamic balance, proprioception, knee and ankle joint integrity, muscle activation and muscle coordination[78,79]. The four-meter walk test was selected as a measure of mobility, leg strength for forward propulsion and vestibular system integrity[80,81]. The four-meter walk test may also be assessing dynamic balance, muscle activation, muscle coordination and joint position sense[80,81]. The timed up and go test was used as a measure of ability to perform activities of daily living, assessing balance, leg power, and obstacle avoidance (by walking around a cone), which has been shown to decrease in individuals with increased postural sway and decreased leg muscle strength[82]. The step test was selected as an assessment of dynamic balance. 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[83]. Finally, the timed loaded standing test was selected as a measure of back extensor muscle endurance, back extensor muscle strength, and trunk muscle activation[84]. The timed loaded standing test may also assess shoulder flexibility, back pain, and static balance. The timed loaded standing test was done in a subset of the population.

3.4.1 Occiput-to-Wall Distance

Occiput-to-wall distance (cm) was used to measure forward head posture, and used as a proxy measure for hyperkyphosis[19]. The participant stood facing away from the wall, with their feet together and heels, back, and shoulders touching the wall. They were asked to look straight ahead to ensure their chin is parallel to the floor and to push their head back towards the wall as far as possible. The zero end of a measuring tape was placed against the wall and the horizontal distance between the wall and the occiput was measured in centimeters, to one decimal point. Occiput-to-wall distance has a high correlation ($r=0.902$ $p<0.001$) with the Flexicurve measure of kyphosis indicating strong concurrent validity of using occiput-to-wall distance to measure hyperkyphosis[85]. The sensitivity and specificity of OWD to detect prevalent thoracic fractures encountered in clinical practice were 41% and 92%, respectively.

3.4.2 Timed Up and Go

The Time Up and Go test was selected as the primary outcome measure as it is associated with almost all of the systems thought to be influenced by forward head posture. Variance in performance on the TUG test would likely reflect the influence of forward head posture on activities of daily living. The Timed Up and Go is a dynamic and functional performance measure, used to measure overall mobility and balance. The Timed Up and Go also measures the ability of an individual to turn 180 degrees with maintaining an upright position[86,87]. 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 Timed Up and Go has shown high reliability (ICC >0.99) and strong validity to the Berg Balance scale (r= -0.81), gait speed (r=-0.61) and the Barthel index (r=-0.78) [82].

3.4.3 Five Times Sit-to-Stand

The five times sit-to-stand test represents functional leg muscle strength [78,79], lower leg power, dynamic balance, proprioception, knee and ankle joint integrity, muscle activation and muscle coordination. 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, did not completely rise from the chair in one minute or if there was concern for the participant's safety. Completion in greater than 15 seconds time is an indicator for fall risk. The five times sit-to-stand test is a reliable measure of lower leg power[88], and a valid measure of dynamic balance and functional mobility in older adults[89].

3.4.4 Four-meter walk test

The Four-meter walk test measures gait speed[80,81], leg strength for forward propulsion and vestibular system integrity. Four-meter walk test is also a measure of dynamic balance. A four-meter straight walking path was marked using tape on the floor. A 1-meter 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 participants were instructed to walk a comfortable walking pace. The test was timed beginning when the first foot crossed the leading edge of the piece of tape that constituted the 4-meter 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, and the fastest time was recorded. Four-meter walk has been shown to have high reliability and validity for measuring gait speed in an older adult population[90]. The four-meter walk test is strongly correlated to the six-minute walk test suggesting strong validity of the four-meter walk test to measure functional capacity[91].

3.4.5 Step Test

The step test measures the speed of performing a dynamic single limb stance task[83,92,93], assessing single leg dynamic balance. The participant stood unsupported with their shoes removed, feet parallel and 10cm 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 return it fully back down to the floor repeatedly as fast as possible for 15 seconds. 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 seconds is recorded for each foot individually, an average number of steps was used in the analysis[92]. The step test is both reliable (ICC>0.98) and a valid measure of lower-limb muscle strength, lower-extremity motor coordination, and correlated with the Berg Balance Scale and walking speed in an older adult population [92,93].

3.4.6 Timed Loaded Standing

The timed loaded standing test was selected as a measure of back extensor muscle endurance, back extensor muscle strength, arm muscle endurance and trunk muscle activation. The timed loaded standing test may also assess shoulder flexibility, back pain, and static balance. The timed loaded standing test measures the time a person can stand while holding a 2 pound dumbbell in each hand with the arms at 90 degree of shoulder flexion, the elbows extended, and the wrists in neutral pronation/supination[84]. Participants are not permitted to proceed with the Timed Loaded Standing if their systolic blood pressure exceeded 200 mmHg[84]. A research assistant demonstrated the task and then the participant performed it. The participant was instructed to stand with their feet hip distance apart, bend the elbows to bring the weights into the shoulders and then extend the arms to 90 degrees of should flexion. When the arms were fully extended the research assistant started the stopwatch. The test was stopped if the participant could not maintain 90 degrees of shoulder flexion or up to two minutes. The timed loaded standing test was both a reliable and a valid measure of physical impairment, functional performance and functional status[84]. The timed loaded standing test was conducted in a subset of participants (38/158), and therefore does not represent the entire cohort.

3.5 Vertebral Fracture Ascertainment

Radiographs (X-rays) were used to confirm the presence of vertebral fractures. An anterior-posterior radiographic image of the lumbar and thoracic spine was conducted in a hospital or clinic by a trained X-ray technician. The standardized protocol was circulated to each site to ensure consistency in ascertainment of the spinal X-ray. If an X-ray had been conducted within the past 6-months, of both the lumbar and thoracic spine, the X-ray was sent to the central radiologist for verification of fracture. A central radiologist read and graded each fracture for each participant's X-ray. The degree of compression was reported based on the Genant vertebral fracture classification[26]. A scoring sheet was completed for each participant, which included the location of fracture, morphology of the fracture and the percent deformity of the fracture (see the sheet in Appendix 2).

3.6 Vertebral Fracture Variables

The number of fractures variable was based on radiographic image. A sum of all fractures for each individual was conducted based on the fracture report from the radiologist. The severity of vertebral fracture was categorized based on the Genant vertebral fracture classification, where a

Grade 1 fracture is <25%, a Grade 2 fracture is 25-40% and a Grade 3 fracture is >40% [26]. Participants were grouped into one of three categories: grade 0-1 fracture(s), grade 2 fracture(s), or at least one grade 3 fracture.

Location of fracture was created as a categorical variable. Location of fracture was categorized by fractures occurring in mid-thoracic region (T4-8), fractures occurring between the thoracolumbar junction (T9-L1) and in the lumbar region (L2-L5). Participants were categorized into one of three categories: thoracic (T4-8), thoracolumbar junction (T9- L1), and lumbar (L2-L5). 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 and L1 was coded: T4-T8=1, T9-L1=1, L2-L5=0. These sites were selected to provide insight into the contribution of location on hyperkyphosis. A category of the thoracic spine was of interest because that is the point of natural kyphotic curve in the spine, and may be exaggerated with vertebral fractures, thereby increasing hyperkyphosis. The thoracolumbar junction was selected because this is the point where the spine changes from a kyphotic to a lordotic curve, changing the loading about those vertebrae. The thoracolumbar junction also had little musculoskeletal support, which may increase fracture risk and contribute to hyperkyphosis. Finally, the lumbar spine was selected because although it may not directly contribute to hyperkyphosis, it was hypothesized that the lumbar spine might have a higher prevalence of fracture from increased forces about those vertebrae, which may have a large influence on physical performance.

3.7 Confounding Variables

Potential confounding variables that were considered for inclusion in the regression models included age, and pain. Age was selected as a confounding variable because of the association with both vertebral fractures and hyperkyphosis, confounding the association between vertebral fractures, hyperkyphosis and physical performance. Pain has been associated with both vertebral fractures and hyperkyphosis, and may confound the relationship of vertebral fracture and hyperkyphosis with physical performance. Age was determined at the baseline visit, using the birth date of the participant. Pain was assessed using a pain scale, which asked the participants to rate their pain during movement, in the past week, on a scale from 0-10, with zero being no pain at all, and 10 being unbearable pain.

3.8 Missing Data

Participants were excluded from the analysis if no baseline data was collected. The larger trial, B3E, required participants to have a radiographically verified vertebral fracture for inclusion into the study. Ascertainment of the X-ray was sometimes completed before the initial study visit, and if the participant did not have a fracture, no baseline assessment was completed. In total, 19 of the 22 excluded participants were due to not having baseline data because there was no radiographic evidence of a vertebral fracture. For one participant, baseline data was collected but components of the data were missing. It occurred for one participant that she or the research assistant felt unsafe performing all of the physical performance tests. She was removed from the analyses. Two participants were excluded from this study because they withdrew consent. Several of the participants were included in this analysis, but had components of their physical assessment missing, specifically in the five times sit-to-stand. Deletion was not a feasible missing data strategy for those who did not complete the five times sit-to-stand as 32 participants were unable to complete the one-time sit to stand test, and therefore did not attempt the five times sit-to-stand. The hot deck imputation approach was used to impute the five times sit-to-stand data[94,95], where the data set was ordered according to fastest to slowest performance on the Timed Up and Go test. The data from the missing five times sit-to-stand cell was input from the cell value immediate prior to the data that was missing. The Timed Up and Go test was used to order the data because it was strongly correlated to the five times sit-to-stand test (Pearson's r= 0.78). The hot deck approach has been used to impute health data without adding large bias or changing the mean[94].

3.9 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 cell counts and percentages in Table 2.The current study was restricted to the number of participants and variables collected in the B3E randomized control trial, and therefore, the current study was based on the 158 participants with any baseline data.

For each of the three objectives, three models were presented. An unadjusted, adjusted, and adjusted including interaction terms models were presented. The unadjusted model presented the associations between the dependent and independent variables. The adjusted model accounted for age and pain during movement as potential confounding variables, and the adjusted with interaction terms accounted for age, and pain during movement as confounding variables and the interactions between number and severity of fracture, number and T4-T8 location, number and T9-L1 location, and number and L2-L5 location.

The first objective was to determine the association between vertebral fracture characteristics (number, severity and location), posture (OWD), and the TUG test. Bivariate correlation analyses were conducted between the dependent variable and each of the independent variables: Pearson's correlation analyses for continuous variables, and Spearman's correlation analyses for the categorical, location, variables. A p value of <0.05 was used as the criteria for statistical significance. No corrections for multiple models for were accounted for, as this thesis was exploratory in nature. Pearson r coefficients were interpreted as follows: >= 0.7 as strong, 0.4-0.69 as moderate, 0.1-0.39 as weak, and < 0.1 as very weak[96]. Bivariate correlation analyses were run to determine the correlation between each of number, severity, location, and OWD with TUG.

A multivariable linear regression was performed with fracture characteristics and OWD as independent variables. The TUG test performance was the dependent variable. A model for the unadjusted, adjusted, and adjusted with interaction terms was generated. Once the model was made, a test of co-linearity was performed. Variables with variable inflation factor (VIF) greater than 5, were considered co-linear and removed. 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[97]. Three final models were presented. In the final models, a p value of <0.05 was considered statistically significant.

The second objective was to determine the association between vertebral fracture characteristics, OWD, and additional physical performance tests including: the five times sit-to-stand, four-meter walk, step test, and timed loaded standing. Bivariate correlation analyses were conducted between the each of the independent variables (number, severity, location and OWD) and each of the dependent variables (five times sit-to-stand, four-meter walk, step test, and timed loaded standing). Pearson's correlation analyses were used for the continuous variables, and Spearman's correlation analyses for the categorical, location, variables. Correlation analyses were used to determine the correlation between each of number, severity, location, and OWD with the additional physical performance measures

For each of the three models, each of the physical performance measures was entered into the model as the dependent variable, creating 12 models. Multivariable linear regression models were generated for each of the unadjusted, adjusted, and adjusted with interaction terms models in each of the physical performance measures. VIF was used, as described above, to remove variables with high co-linearity. Once the VIF was less than 5 for each of the variables in the model, the remaining variables were input into a multivariable regression model. A final unadjusted, final adjusted, and final adjusted with interaction terms model was conducted with a p value of <0.05 as the criteria for statistical significance.

The third objective was to determine the association between vertebral fracture characteristics and OWD. Pearson's correlation analyses were used for continuous variables, and Spearman's correlation analyses were used for the categorical, location, variables, to determine the correlation between each vertebral fracture characteristic (number, severity, T4-T8, T9-L1, and L2-L5) and OWD to determine the correlation of these variables.

Three multivariable regression models were generated, one for unadjusted, one for adjusted and one for adjusted accounting for interaction terms. OWD was the dependent variable and number of fracture, severity of fracture, T4-T8, T9-L1, and L2-L5, were the independent variables for the unadjusted model. The adjusted model accounted for age, and pain during movement; and final model accounted for the confounding variables and the interaction between number x severity, number x T4-T8, number x T9-L1, and number x L2-L5. VIF was used initially to remove variables with high co-linearity as described above. A final unadjusted and final adjusted multivariable linear regression model was conducted with a p value of <0.05 as statistically significant.

Chapter 4

Results

During the recruitment period from September 2013 until November 2015, 181 participants were deemed eligible and underwent an X-ray. Of the 181 participants, 22 (12%) did not complete a baseline assessment either due to a lack of vertebral fracture (exclusion criteria for the B3E trial), or the participant did not consent to participate. 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. All analyses were completed in 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. On average, participants had 2 (± 1.8) fractures, 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). The participants had, on average, 2.5(± 2) comorbidities and were taking 5.3(± 4) medications and supplements (Table 2). The average OWD was 5.7 cm and it's been suggested that an OWD of greater than 5 cm is indicative of hyperkyphosis[98]. Table 3 shows the mean and standard deviation of the five physical performance assessments in all participants, participants that don't report using a gait aid and in participants using a gait aid. Figure 6 represents the frequency of vertebral fractures by the participants, and figure 7 represents the frequency of fractures by location. Figure 8 represents the frequency of occiput-to-wall distance.

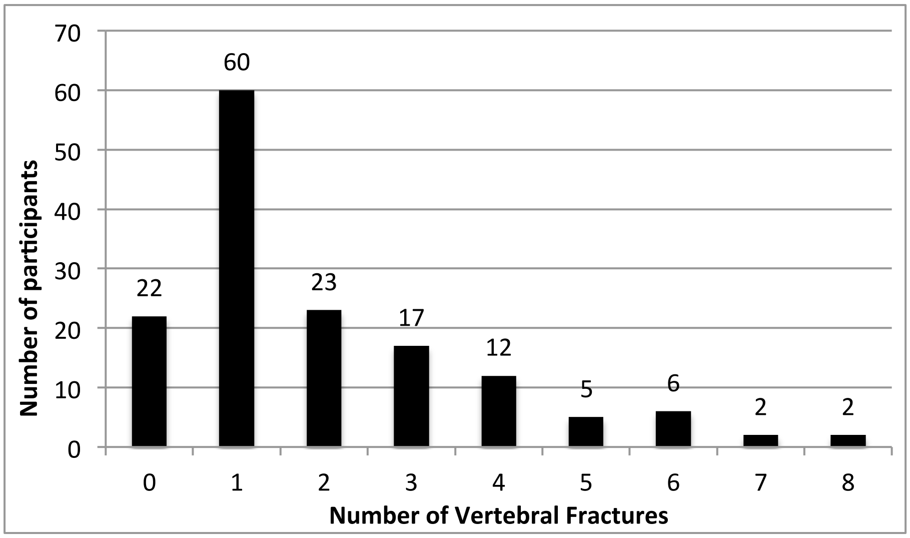

Figure 6: Frequency of fractures, representing the number of participants with the number of fracture ranging from 0-8 fractures.

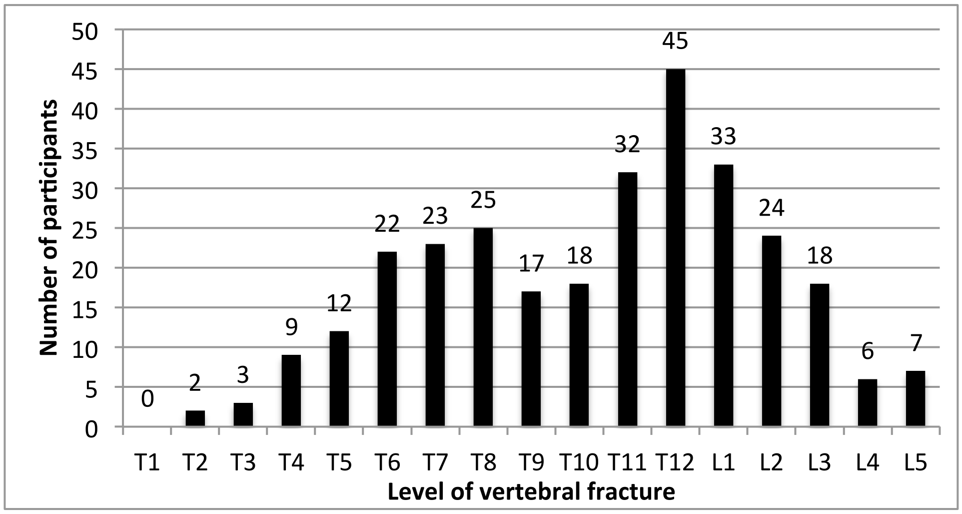

Figure 7: Frequency of fractures by location of vertebral fracture, representing the number of participants with a fracture in each location from T1-L5

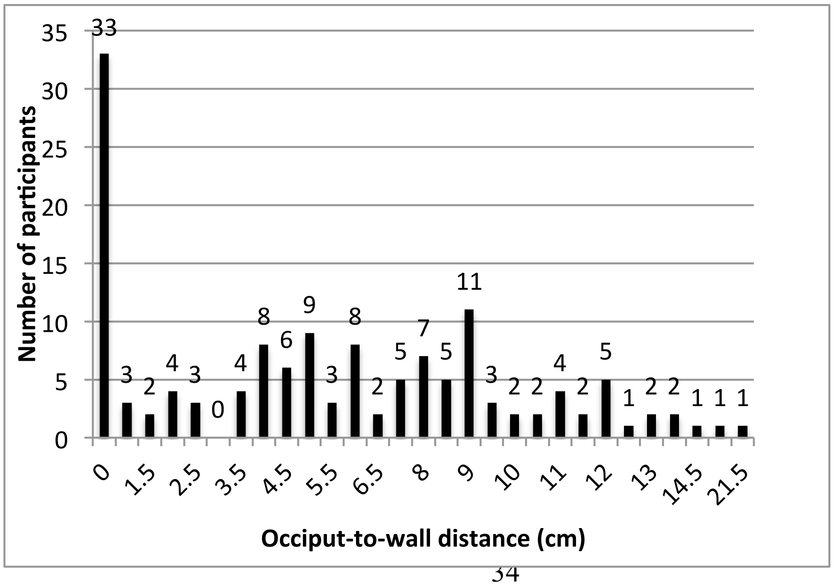

Figure 8: Frequency of occiput-to-wall distance, representing the number of participants with the distance from their occiput bone to the wall ranging from 0 – 21.5 cm.

4.1 Objective 1: Associations between fracture characteristics and occiput-to-wall distance

The correlation between OWD and number, T9-L1, L2-L5, severity of fracture and pain during movement were r= 0.29, r= 0.17, r= 0.16, r= 0.24 and r= 0.21 respectively. T4-T8, and age were not correlated with OWD (Table 4).

The unadjusted multivariable regression model was statistically significant ($p<0.01$) accounting for 10% of the variance in OWD. Number of fractures was the only variable that was independently associated with OWD ($p<0.04$), such that for every fracture, OWD increased by 0.82 centimeters (Figure 9). None of the other fracture characteristics were significantly associated with OWD (Table 5).

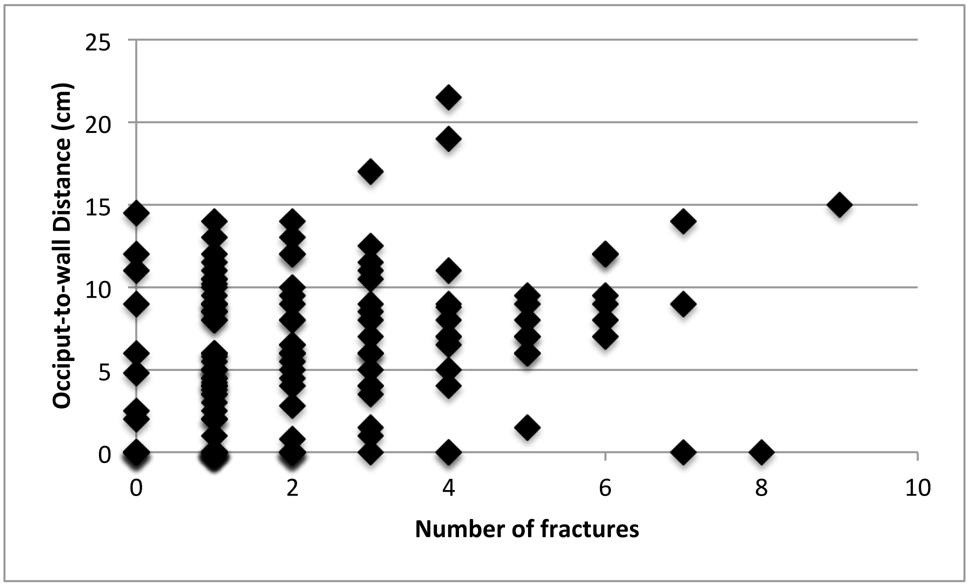

Figure 9: Relationship between occiput-to-wall distance and number of fractures.

The adjusted multivariable regression model was statistically significant ($p<0.02$) and accounted for 14% of the variability in OWD. Pain during movement and severity of fracture category were independently associated with OWD. For every point increase in pain, OWD increased by 0.30 centimeters; and for every severity category increase, OWD increased by 1.08 centimeters.

Number of fracture, location of fracture and age were not independently associated with OWD (Table 6).

The adjusted model with interaction terms was statistically significant ($p<0.01$), and accounted for 16% of the variability in OWD. In this model, pain during movement was the only variable independently associated with OWD ($p<0.04$). For every point increase in pain, there was a 0.28-centimeter increase in OWD. All of the other variables including all of the fracture characteristics, age, and interaction terms were not statistically significant (Table 6).

4.2 Objective 2: Association between fracture characteristics, occiput-to-wall distance and Timed Up and Go test

There was a significant, weak, positive association between TUG time and number of fractures, L2-L5 fractures, severity of fractures and OWD. All associations were weak such that the association with OWD was $r= 0.37$, and for the fracture characteristics the associations ranged from $r= 0.16$- 0.17 (Table 7). TUG was also significantly, but weakly, associated with pain during movement at $r= 0.23$.

The unadjusted multivariable model for TUG performance was statistically significant ($p <0.001$) and accounted for 15% of the variability in TUG. OWD was the only variable that was independently associated with TUG ($p <0.001$). For every centimeter increase in OWD, TUG time increased by 0.29 seconds (Table 8). None of the fracture variables were independently 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 seconds, and for every point increase in pain TUG time increased by 0.32 seconds. Age, and the fracture characteristics were not independently associated with TUG performance (Table 9).

In the final multivariable regression model, interactions between number and location of fractures, and number and severity of fractures were accounted for in addition to the confounding variables (Table 9). The model was statistically significant ($p< 0.001$), and accounted for 22% of the variance in TUG. OWD and pain during movement were independently associated with TUG ($p<0.001$ and $p< 0.003$, respectively). For every centimeter increase in OWD, TUG time increased by 0.26 seconds. For every point increase in pain TUG time increased by 0.34 seconds. All the other variables, including the fracture characteristics, age and interaction terms were not significant in the model.

4. 3 Objective 3: Association between fracture characteristics, occiput-to-wall distance and additional selected physical performance assessments

4.3.1 Five Times Sit-to-Stand Test

There was a weak positive correlation between five times sit-to-stand test and OWD ($r= 0.27$),and L2-L5 ($r= 0.21$), (Table 10). 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 correlated 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 seconds. The association with five times sit-to-stand and L2-L5 approached significance ($p=0.06$), and for every fracture in this location, five times sit-to-stand time increased by 2.93 seconds. None of the other fracture characteristics were statistically significant (Table 11).

In the adjusted multivariable regression model, 16% of the variance was explained when age and pain during movement were included in the model (Table 12). 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 seconds. Pain during movement and L2-L5 location approached significance at $p=0.07$ and $p=0.06$ respectively. 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 seconds.

When interaction terms were entered into the model in addition to confounding variables, 18% of the variability in five times sit-to-stand was accounted for ($p<0.01$). OWD was the only variable that was significantly associated with five times sit-to-stand in this model ($p<0.01$), but pain during movement approached significance ($p=0.07$). All other variables were not statistically significant (Table 12).

4.3.2 Four-meter Walk Test

There was a weak significant correlation between the four-meter walk test and fracture severity category ($r= 0.22$), OWD ($r= 0.38$), and pain during movement ($r= 0.32$) (Table 10). 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 category were statistically significant at $p<0.001$ and $p=0.03$, respectively. The association between T4-T8 approached statistical significance ($p=0.09$) (Table 11).

The adjusted multivariable regression model was statistically significant, accounting for 24% of the variability in the four-meter walk test ($p<0.001$). OWD ($p<0.001$), fracture severity category ($p<0.01$) and pain during movement ($p<0.001$) were all significantly associated with the four-meter walk test. The association between T4-T8 and T9-L1 approached statistical significance ($p=0.09$ and $p=0.10$, respectively) (Table 12).

The adjusted model accounting for interaction terms was statistically significant and accounted for 25% of the variability in the four-meter walk test. OWD and pain during movement were the only variables that were independently associated with the four-meter walk test. None of the fracture characteristics, or interaction terms were significantly associated with the four-meter walk test (Table 12).

4.3.3 Step Test

There was a moderate negative correlation between the step test and OWD (r= -0.41), and negative weak correlation between the step test and pain during movement (r= -0.24) (Table 10). 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 11).

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 step test number decreased by 0.29 steps. None of fracture characteristics, or age, was significantly associated with step test performance (Table 12).

The adjusted model accounting for interaction terms was statistically significant and accounted for 22% of the variability in the step test (p<0.001). Pain during movement and OWD remained the only variables independently associated with step test. There was a positive association between severity of fracture, T4-T8, age, number x T4-T8, and number x L2-L5; however, none of these associations were statistically significant (Table 12).

4.3.4 Timed Loaded Standing Test

Analyses in the timed loaded standing test (TLS) was done in a subset of the population, 38 participants were included in these models. There was a weak negative association between the TLS and T4-T8 (r= -0.28), L2-L5 (r= -0.29), and pain during movement (r= -0.54) (Table 10).

There was no statistically significant association between TLS and fracture characteristics and OWD with or without adjusting for the confounding variables (Table 11 and Table 12). Number of fractures was removed from these analyses due to a high variance inflation factor (VIF). This was the only variable in all models to have a high VIF. In the unadjusted multivariable regression model, 22% of the variance in TLS was accounted for, but this was not statistically significant ($p<0.15$). None of the variables in the unadjusted model were independently associated with TLS.

In the adjusted model (Table 12), 27% of the variance was accounted for, but this was not statistically significant. The adjusted model accounting for interaction terms was statistically significant ($p<0.04$) and accounted for 56% of the variance in TLS. T4-T8 ($p<0.001$), and pain during movement ($p<0.02$), the interaction between number x T4-T8 ($p<0.01$) and the interaction between number x L2-L5 ($p<0.05$) were independently associated with TLS. For fractures in T4-T8, time on the TLS decreased by 105.38 seconds. All other fracture characteristics, OWD, age and the interaction between number x severity and number x T9-L1, were not statistically significant (Table 12).

4.4 Correlations between physical performance measures

Associations between the physical performance assessments are presented in Table 13. TUG was strongly associated with the five times sit-to-stand test (r= 0.77) and the four-meter walk test (r= 0.76). There was a moderate negative association between the TUG and the step test (r= -0.54). The TLS test was the only test not significantly associated with any of the other physical performance measures (r= -0.05-0.23). The five times sit-to-stand test was moderately, negatively, associated with the step test (r= 0.45) and four-meter walk (r= 0.52), and the step test and four meter walk tests were both moderately, negatively, associated (r= -0.42) (Table 13).

Chapter 5
Discussion

Our findings demonstrated that OWD explained a greater amount of the variance in physical performance, particularly TUG and four-meter walk, than fracture characteristics in older women with a suspected vertebral fracture. OWD was shown to contribute to dynamic balance, such that greater OWD was associated with worse step test performance. As well, OWD was associated with the five times sit-to-stand, four-meter walk, and TUG suggesting that lower limb strength, and gait speed are also influenced by OWD. Pain during movement contributed to physical performance variability, as it was significantly associated with TUG, four-meter walk and step test.

As we hypothesized, number of fractures was positively associated with OWD in our older women with a suspected vertebral fracture, however, unlike our hypothesis; severity and location variables were not significantly associated with OWD. One study looked at the association between hyperkyphosis and risk of future osteoporotic fracture, and found that individuals with hyperkyphosis had a 1.7-fold of a future fracture, independent of age, prior fracture, and hip or spine BMD[15]. Since it is hypothesized that hyperkyphosis results from vertebral fractures, the researchers considered history of spine fracture in an adjusted model and found no difference, suggesting that spine fractures do not contribute to hyperkyphosis[15,99]. It could be that asymptomatic vertebral fractures, back extensor strength, non-vertebral fractures, declines in physical activity or type of fracture are contributing more to hyperkyphosis than symptomatic vertebral fractures.

Types of fracture, such as anterior wedge fractures are thought to contribute to hyperkyphosis, and therefore may promote greater OWD. One study suggested that the type of fracture contributes to OWD[52]. It was found that individuals with a wedge, endplate and crush fracture had an average OWD of 4.6 cm, 5.4 cm and 8.7 cm respectively[52]. Future studies should aim to replicate the findings and determine if the type of fracture contributes to OWD, and whether type of fracture contributes more to variability in OWD than number, severity and location of fractures. Vertebral disc integrity also plays a large role in maintaining postural alignment[100], which was not assessed in the current study, but it may be an important variable contributing to the association between vertebral fractures and OWD. To date, a few studies have found that there was an association between prevalent vertebral fractures and hyperkyphosis[52,101]. However, other studies suggest there is no association[12,19,51,53,98]. One study identified an association between kyphosis and incident vertebral fractures, such that every 10° increase in kyphosis angle was associated with a 22% increase in new vertebral fracture[101]. However, after adjusting for prevalent vertebral fractures, the association between hyperkyphosis and incident vertebral fractures was no longer statistically significant[101]. Although it would be expected that hyperkyphosis increases the loads on the anterior portion of the spine, increasing the risk of fracturing, but it was found that hyperkyphosis did not predict incident fractures. It is likely that spinal muscles have adapted to the change in posture, and reduce the load on the spine, attenuating the risk of fracturing. Even further, women with severe hyperkyphosis (greater than 53° kyphosis angle) had a 50% increased risk of non-vertebral fractures, independent of other known fracture risk factors (age, BMD) [102]. It is likely that the postural changes from hyperkyphosis are influencing the center of mass, translating it anteriorly, closer to the edge of stability, thereby affecting balance, and mobility, increasing the risk of falling and therefore increasing the risk of non-vertebral fractures. The current study confirms that OWD may be affecting balance and mobility.

Greater OWD appears to have an independent association with mobility impairments (i.e. slower TUG and four-meter walk time) in women with a suspected vertebral fracture. Kyphosis has been shown to influence mobility[12,19,20,57,103], a component of the TUG test. Katzman et al. (2011) demonstrated that kyphosis significantly contributed to TUG[36], such that per every standard deviation increase in kyphosis angle, TUG time increased by 0.11 seconds. We demonstrated that for every standard deviation increase in OWD, TUG time increased 0.32 seconds. The average TUG time 11.9 seconds, and a TUG time of 10 seconds is a suggested cut-off score indicating risk of falls for individuals with hip osteoarthritis[104], suggesting that the average participant, in the current study, is at an increased risk of falling, and for every centimeter increase in OWD, their risk of falling further increases. Mobility may be influenced by both balance impairments from a forward flexed posture in individuals with hyperkyphosis[11,19,20], and gait unsteadiness from an increase in gait variability[12,57]. OWD explained more variance in four-meter walk test than other variables known to influence mobility including pain, age, and vertebral fractures, suggesting a link between posture and mobility in women with a suspected vertebral fracture. Individuals with osteoporosis and kyphosis typically have slower gait and shorter stride length[20], increasing fall risk. However 52 participants reported using a gait aid during their daily activities, but only 11 participants used the gait aid during the TUG test. Mobility impairments may be exacerbated in this population due to individuals not using a gait aid when they typically use gait aid in daily activity. Individuals with more variable gait patterns are more cautious, 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 leg strength, such as the five times sit-to-stand, or the TUG, which was observed in the current study. Individuals with osteoporosis and kyphosis have been shown to have lower muscle strength[11,16,20]. Lower leg strength is associated with a decreased ability to control the center of mass within the base of support, resulting in more mediolateral displacement and greater mediolateral velocity[20]. Individuals with osteoporosis and hyperkyphosis typically demonstrate reduced hip abductor strength, knee extensor strength, ankle dorsiflexion, grip strength[20], and quadriceps strength[67] compared to controls without osteoporosis or hyperkyphosis. OWD and pain during movement were independently associated with five times sit-to-stand performance in our study, suggesting that performance variability is linked to lower muscle strength potentially due to pain-related inactivity, or posture changes. Greater OWD may in part be due to a decrease in postural muscle endurance, which was hypothesized in this thesis. Although the current study showed no association between OWD and TLS, the findings may have been due to the smaller sample size in TLS. Jonsson (2006) found that older adults had lower postural control than younger adults, potentially affecting their postural steadiness[105], and physical performance, specifically to get in and out of a chair. Lower postural muscle activation in older adults contributes to balance limitations and falls risk [105].

Dynamic balance is negatively affected by kyphosis in women with osteoporosis because their center of mass is pushed closer to the edge of their stability limits. In our study, OWD was shown to modestly contribute to the step test performance, a measure of dynamic balance. 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[105]. Furthermore, studies by Lynn et al. (1997) and Jonsson (2006) exhibited that older adults may unload too soon with respect to displacement of center of mass (COM), leading to more postural adjustments in order to be able to control the COM[11,105]. In contrast, younger adults demonstrate a longer unloading phase and larger temporal delay between attainment of the maximal vertical and lateral forces[11,105]. Thus, it is not surprising that OWD was associated with dynamic balance assessments in our study. Although there was no association between the independent fracture characteristics and step test, it could be that vertebral fractures are contributing to OWD influencing the shift in COM and dynamic balance. Further insight into types of fracture (anterior wedge, concavity, or compression) could provide insight into whether vertebral fractures are influencing OWD and physical performance. Future work should examine those associations.

Pain was moderately (r= 0.23-0.54) associated with the TLS, TUG, and four-meter walk tests. Individuals with vertebral fractures typically report feeling pain and may limit physical activity in an attempt to reduce pain[69]. 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[32]. The lumbar vertebrae have high threshold, and slow conduction velocity mechanosenstive afferent units, which may serve as nocioceptors in the lumbar facet joints, resulting in low back pain[106]. 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 is a key variable to address when designing interventions to improve physical performance.

The current study found that OWD was a moderate-to-weak correlate of physical performance, and contributed more to physical performance variance than vertebral fracture characteristics. Alternatively, Greig et al. (2007) found that individuals with osteoporosis had balance impairments, as measured by center of pressure on a force plate, due to presence of a vertebral fracture not hyperkyphosis[51]. Such conflicting findings may be due to their low sample size (n=22), and lack of adjustment for pain[51]. As well, using a force plate for balance assessments may have allowed for identification of preliminary balance impairments as older adults experience kinematic and force variability in their balance before it is clinically visible[105]. Therefore, the step test may not be sensitive enough to detect the subtle balance instabilities observed in individuals with vertebral fractures.

Fracture characteristics were either not associated or modestly associated with physical performance. It was hypothesized that a greater number, greater severity and more mid-thoracic vertebral fractures would be associated with worse physical performance; however, our results demonstrated that only severity of fracture was significantly associated with the four-meter walk test. Previous studies have shown that individuals with vertebral fractures performed worse on physical performance assessments than individuals without vertebral fractures[14, 107]. Risk of poor performance in the chair stand and walking test increased with increasing number of fracture (OR=1.60) [22,107].

Severity of fracture appears to have a greater influence on physical performance than number of fracture, such that the risk of poor chair test performance (OR= 2.16) in individuals with mild to severe vertebral fractures; and in the walking test risk of poor performance increased from OR= 0.97 in severe fracture[107]. In our study, neither number nor severity was significantly associated with five times sit-to-stand test. Severity of fracture was statistically associated with the four-meter walk test in the adjusted and unadjusted models, but not when interaction terms were included in the model. Van der Jagt-Willems et al. (2012) also did not find a significant difference in performance on the TUG when comparing individuals with and without vertebral fractures[22]. Plujim et al., did not use the Genant fracture grading system[26], which was done in the current study and in the van der Jagt-Willems study. Plujim et al study categorized grade three fractures as >30% compression[107], whereas the Genant fracture grading system considers grade three fractures as >40%[26]. The difference in systems may be sufficient to allow for inclusion of a greater number of participants in the grade 3 fracture category allowing for a stronger association between severity and physical performance, as was observed by Pluijm et al[107].

Posture re-training seems to be a plausible intervention to improve physical function in older adults, due to the high association of OWD with physical performance measures, and the lack of association between fracture characteristics and physical performance measures. The association between OWD and physical performance suggests that as OWD increases as performance on the selected physical performance assessment decreases. Therefore, if an intervention can reduce OWD, it’s possible that physical performance may improve. Exercise interventions have been suggested as a conservative rehabilitation strategy to improve hyperkyphosis. A review of rehabilitation strategies for hyperkyphotic posture in older adults suggests that exercise based interventions, like yoga and back extensor exercises, show promise for improving health outcomes for individuals with hyperkyphosis[108], further work needs to be done to determine the influence of yoga and back extensor exercises on posture. However, many of the exercise interventions were of small sample size and short in duration, so the efficacy and feasibility of exercise interventions to improve hyperkyphosis needs to be confirmed. The studies of highest quality suggest that spinal extensor exercises and yoga may reduce hyperkyphosis[109,110]. Future studies should advance this work by determining how improving hyperkyphosis affects performance on physical assessments.

Improving hyperkyphotic posture may improve physical performance measures. A pilot study aimed to improve hyperkyphosis through back extensor strengthening exercises, spinal mobility, and spinal alignment activities[111], demonstrated significant improvements in physical performance assessments (Physical Performance Test and Jug Test), suggesting that improving hyperkyphosis can also improve physical function. Another study found no significant improvement in physical performance after a yoga intervention, despite seeing significant improvements in hyperkyphosis[109]. The yoga-intervention study was of higher quality, with more participants, and a longer intervention[109], however, yoga may not have been a targeted enough of an intervention to improve overall physical function. A larger study designed to detect differences in physical function after improving hyperkyphosis is necessary to determine if posture retraining is sufficient to influence the declines in physical performance associated with hyperkyphosis. It may be necessary to design multidimensional exercise programs targeting back extensor endurance, lower extremity strength and endurance, upper extremity strength and endurance, flexibility and aerobic capacity to address the many facets of physical function affected by hyperkyphosis (lower limb strength, lower limb power, back extensor endurance, dynamic balance, aerobic fitness).

There were several limitations to this study. The use of OWD to assess hyperkyphosis may not be sensitive enough to detect subtle posture changes, however, OWD represents a safer, 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; however, balance, as measured by the step test, was not assessed in isolation in this study. This study was pragmatic in nature, and therefore a functional measure of balance, like the step test, was suitable to allow for stronger conclusions on function during activities of daily living. Another limitation is that fear of falling was not considered as a confounding variable in this study. Fear of falling has been shown to contribute to stride-to-stride variability in older adults[67]. Individuals with unsteady gait have lower confidence in performing daily routine activities due to a fear of falling, resulting in balance impairments. Future work should evaluate the relationship between fear of falling and clinical performance assessments. The study population was limited to older women with a suspected vertebral fracture. Therefore, the results cannot be generalizable 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. As well, women in B3E were included with suspicion of a grade 2 vertebral fracture, suggesting that those individuals with a mild fracture may have presented with worse posture and worse physical ability than women that may not have been suspected of having a grade 2 vertebral fracture. Number, severity and location were used, in this study, to categorize vertebral fractures, however, the type of fracture was not taken into account (anterior vs posterior compression). Type of fracture may provide further insight into those that have hyperkyphosis from a fracture and those that do not, and should be considered in future studies.

Finally, this thesis was based off of the data collected in a randomized controlled trial, Build Better Bones with Exercise, and was therefore limited to the data collected in that study. Although this was a large data set, allowing for me to answer my primary research question which was: “Do fracture characteristics or OWD explain more variance in physical performance measures in women with a suspected vertebral fracture, over the age of 65?”, this data base was not able to provide the "why" to its findings. Given the opportunity to design a new study, one would be created to not only answer the primary research question but also provide some insight into why we saw the findings that we found. Firstly, both OWD and radiographic hyperkyphosis would be determined to understand the correlation of using OWD compared to common method of radiographically measuring hyperkyphosis (Cobb's angle). Secondly, based on the framework, it was hypothesized that sensory impairments are contributing to physical performance declines. No study has looked at the influence of manipulating sensory systems and seeing how balance, muscle strength, and muscle endurance are affected. Incorporating the Computerized Dynamic Posturography (CDP), which incorporates tests of both sensory organization and motor coordination would provide insight into how the subject is using available sensory information to maintain balance and function. Otherwise pain was assessed in the current study as well as assessments of muscle strength, muscle endurance and cardiovascular health were pragmatically evaluated.

Conclusion

OWD was significantly associated with each of the physical performance tests measured in this study, except for timed loaded standing. OWD explained more variance in TUG, five times sit-to-stand, four-meter walk and step test than vertebral fracture characteristics, including number, severity and location of fractures. Some vertebral fracture characteristics, mainly 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. Fracture characteristics were significantly associated with OWD, suggesting a link between vertebral fracture severity, location, and number and posture in older women with a suspected vertebral fracture. Therefore, exercise interventions to improve physical performance should target posture re-training through a multidimensional exercise program, which may include exercises that target leg strength, back extensor strength and endurance, and balance) in individuals with vertebral fractures.

1. Kanis JA. Diagnosis of osteoporosis and assessment of fracture risk. *The Lancet*. 2002;359(9321):1929-1936.

2. Ensrud KE. Epidemiology of fracture risk with advancing age. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*. 2013;68(10):1236-1242.

3. Papaioannou A, Morin S, Cheung AM, et al. 2010 clinical practice guidelines for the diagnosis and management of osteoporosis in canada: Summary. *CMAJ*. 2010;182(17):1864-1873.

4. Leslie WD, Morin SN. Osteoporosis epidemiology 2013: Implications for diagnosis, risk assessment, and treatment. *Curr Opin Rheumatol*. 2014;26(4):440-446.

5. Prior JC, Langsetmo L, Lentle BC, et al. Ten-year incident osteoporosis-related fractures in the population-based canadian multicentre osteoporosis study - comparing site and age-specific risks in women and men. *Bone*. 2015;71:237-243.

6. Seeman E. Bone quality: The material and structural basis of bone strength. *J Bone Miner Metab*. 2008;26(1):1-8.

7. Cheung AM, Detsky AS. Osteoporosis and fractures: Missing the bridge? *JAMA*. 2008;299(12):1468-1470.

8. Melton Iii L, Atkinson E, Cooper C, O’Fallon W, Riggs B. Vertebral fractures predict subsequent fractures. *Osteoporosis Int*. 1999;10(3):214-221.

9. Smit TH, Odgaard A, Schneider E. Structure and function of vertebral trabecular bone. *Spine*. 1997;22(24):2823-2833.

10. Cooper C, Atkinson EJ, O'Fallon WM, Melton III LJ. Incidence of clinically diagnosed vertebral fractures: A population-based study in rochester, minnesota, 1985-1989. *Journal of Bone and Mineral Research*. 1992;7(2):221-227.

11. Lynn SG, Sinaki M, Westerlind KC. Balance characteristics of persons with osteoporosis. *Arch Phys Med Rehabil*. 1997;78(3):273-277.

12. De Groot MH, van der Jagt-Willems HC, van Campen JPCM, Lems WF, Beijnen JH, Lamoth CJC. A flexed posture in elderly patients is associated with impairments in postural control during walking. *Gait and Posture*. 2014;39(2):767-772.

13. Cortet B, Roches E, Logier R, et al. Evaluation of spinal curvatures after a recent osteoporotic vertebral fracture. *Joint Bone Spine*. 2002;69(2):201-208.

14. Briggs AM, Van Dieën JH, Wrigley TV, et al. Thoracic kyphosis affects spinal loads and trunk muscle force. *Phys Ther*. 2007;87(5):595-607.

15. Huang M-, Barrett-Connor E, Greendale GA, Kado DM. Hyperkyphotic posture and risk of future osteoporotic fractures: The rancho bernardo study. *Journal of Bone and Mineral Research*. 2006;21(3):419-423.

16. Liu-Ambrose T, Eng JJ, Khan KM, Carter ND, McKay HA. Older women with osteoporosis have increased postural sway and weaker quadriceps strength than counterparts with normal bone mass: Overlooked determinants of fracture risk? *J Gerontol Ser A Biol Sci Med Sci*. 2003;58(9):862-866.

17. Baert V, Gorus E, Mets T, Bautmans I. Motivators and barriers for physical activity in older adults with osteoporosis. *Journal of Geriatric Physical Therapy*. 2015.

18. Kanis JA, Borgstrom F, De Laet C, et al. Assessment of fracture risk. *Osteoporosis Int*. 2005;16(6):581-589.

19. Balzini L, Vannucchi L, Benvenuti F, et al. Clinical characteristics of flexed posture in elderly women. *J Am Geriatr Soc*. 2003;51(10):1419-1426.

20. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: Significance of kyphotic posture and muscle strength. *Osteoporosis Int*. 2005;16(8):1004-1010.

21. Riggs BL, Melton III LJ. The worldwide problem of osteoporosis: Insights afforded by epidemiology. *Bone*. 1995;17(5 SUPPL. 1):S505-S511.

22. van der Jagt-Willems HC, van Hengel M, Vis M, et al. Why do geriatric outpatients have so many moderate and severe vertebral fractures? exploring prevalence and risk factors. *Age Ageing*. 2012;41(2):200-206.

23. Lindsay R, Silverman SL, Cooper C, et al. Risk of new vertebral fracture in the year following a fracture. *J Am Med Assoc*. 2001;285(3):320-323.

24. Goodmurphy C. Anatomy of the spine. *Back Pain: A Guide for the Primary Care Physician*. 2005:29.

25. El-Khoury GY, Whitten CG. Trauma to the upper thoracic spine: Anatomy, biomechanics, and unique imaging features. *Am J Roentgenol*. 1993;160(1):95-102.

26. Genant HK, Jergas M, Palermo L, et al. Comparison of semiquantitative visual and quantitative morphometric assessment of prevalent and incident vertebral fractures in osteoporosis. *J Bone Miner Res*. 1996;11(7):984-996.

27. Melton LJ, Kan SH, Frye MA, Wahner HW, O'fallon WM, Riggs BL. Epidemiology of vertebral fractures in women. *Am J Epidemiol*. 1989;129(5):1000-1011.

28. Antonacci MD, Hanson DS, Leblanc A, Heggeness MH. Regional variation in vertebral bone density and trabecular architecture are influenced by osteoarthritic change and osteoporosis. *Spine*. 1997;22(20):2393-2402.

29. Banse X, Devogelaer JP, Munting E, Delloye C, Cornu O, Grynpas M. Inhomogeneity of human vertebral cancellous bone: Systematic density and structure patterns inside the vertebral body. *Bone*. 2001;28(5):563-571.

30. McCubbrey DA, Cody DD, Peterson EL, Kuhn JL, Flynn MJ, Goldstein SA. Static and fatigue failure properties of thoracic and lumbar vertebral bodies and their relation to regional density. *J Biomech*. 1995;28(8):891-899.

31. Nepper-Rasmussen J, Mosekilde L. Local differences in mineral content in vertebral trabecular bone measured by dual-energy computed tomography. *Acta Radiol*. 1989;30(4):369-371.

32. Briggs AM, Wrigley TV, Van Dieën JH, et al. The effect of osteoporotic vertebral fracture on predicted spinal loads in vivo. *European Spine Journal*. 2006;15(12):1785-1795.

33. Ismail AA, Cooper C, Felsenberg D, et al. Number and type of vertebral deformities: Epidemiological characteristics and relation to back pain and height loss. *Osteoporosis Int*. 1999;9(3):206-213.

34. Van Der Klift M, De Laet CEDH, McCloskey EV, Hofman A, Pols HAP. The incidence of vertebral fractures in men and women: The rotterdam study. *J Bone Miner Res*. 2002;17(6):1051-1056.

35. Christiansen BA, Bouxsein ML. Biomechanics of vertebral fractures and the vertebral fracture cascade. *Curr Osteoporosis Rep*. 2010;8(4):198-204.

36. Katzman WB, Vittinghoff E, Kado DM. Age-related hyperkyphosis, independent of spinal osteoporosis, is associated with impaired mobility in older community-dwelling women. *Osteoporosis Int*. 2011;22(1):85-90.

37. Solomonow M, Zhou B-, Baratta RV, Lu Y, Harris M. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. loss of reflexive muscular stabilization. *Spine*. 1999;24(23):2426-2434.

38. Adams MA, Dolan P, Hutton WC. Diurnal variations in the stresses on the lumbar spine. *Spine*. 1987;12(2):130-137.

39. Biering-Sorensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine*. 1984;9(2):106-119.

40. Adams MA, Doland P, Hutton WC, Porter RW. Diurnal changes in spinal mechanics and their clinical significance. *J BONE JT SURG SER B*. 1990;72(2):266-270.

41. Silverman S. The clinical consequences of vertebral compression fracture. *Bone*. 1992;13:S27-S31.

42. Nevitt MC, Ettinger B, Black DM, et al. The association of radiographically detected vertebral fractures with back pain and function: A prospective study. *Ann Intern Med*. 1998;128(10):793-800.

43. Sanchez-Zuriaga D, Adams MA, Dolan P. Is activation of the back muscles impaired by creep or muscle fatigue? *Spine (Phila Pa 1976)*. 2010;35(5):517-525.

44. Cao D-, Pickar JG. Lengthening but not shortening history of paraspinal muscle spindles in the low back alters their dynamic sensitivity. *J Neurophysiol*. 2011;105(1):434-441.

45. Dolan KJ, Green A. Lumbar spine reposition sense: The effect of a 'slouched' posture. *Man Ther*. 2006;11(3):202-207.

46. Edmondston S, Waller R, Vallin P, Holthe A, Noebauer A, King E. Thoracic spine extension mobility in young adults: Influence of subject position and spinal curvature. *J Orthop Sports Phys Ther*. 2011;41(4):266-273.

47. Park K-, Oh J-, An D-, et al. Difference in selective muscle activity of thoracic erector spinae during prone trunk extension exercise in subjects with slouched thoracic posture. *PM R*. 2015;7(5):479-484.

48. Dolan P, Adams MA. Repetitive lifting tasks fatigue the back muscles and increase the bending moment acting on the lumbar spine. *J Biomech*. 1998;31(8):713-721.

49. Adams MA, Dolan P. Time-dependent changes in the lumbar spine's resistance to bending. *Clin Biomech*. 1996;11(4):194-200.

50. Solomonow M, Baratta RV, Banks A, Freudenberger C, Zhou BH. Flexion-relaxation response to static lumbar flexion in males and females. *Clin Biomech*. 2003;18(4):273-279.

51. Greig AM, Bennell KL, Briggs AM, Wark JD, Hodges PW. Balance impairment is related to vertebral fracture rather than thoracic kyphosis in individuals with osteoporosis. *Osteoporosis Int*. 2007;18(4):543-551.

52. Siminoski K, Warshawski RS, Jen H, Lee K-. The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: Comparison of direct and indirect kyphosis measures. *Journal of Musculoskeletal Neuronal Interactions*. 2011;11(3):249-256.

53. Ribom EL, Kindmark A, Ljunggren Ö. Hyperkyphosis and back pain are not associated with prevalent vertebral fractures in women with osteoporosis. *Physiother Theory Pract*. 2014;31(3):182-185.

54. Delmas P, Genant H, Crans G, et al. Severity of prevalent vertebral fractures and the risk of subsequent vertebral and nonvertebral fractures: Results from the MORE trial. *Bone*. 2003;33(4):522-532.

55. Nevitt M, Ross P, Palermo L, et al. Association of prevalent vertebral fractures, bone density, and alendronate treatment with incident vertebral fractures: Effect of number and spinal location of fractures. *Bone*. 1999;25(5):613-619.

56. Kado DM, Huang MH, Nguyen CB, Barrett-Connor E, Greendale GA. Hyperkyphotic posture and risk of injurious falls in older persons: The rancho bernardo study. *J Gerontol A Biol Sci Med Sci*. 2007;62(6):652-657.

57. Granito RN, Aveiro MC, Renno ACM, Oishi J, Driusso P. Comparison of thoracic kyphosis degree, trunk muscle strength and joint position sense among healthy and osteoporotic elderly women: A cross-sectional preliminary study. *Arch Gerontol Geriatr*. 2012;54(2):e199-e202.

58. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. *Neurobiol Aging*. 1989;10(6):727-738.

59. Fox CR, Paige GD. Effect of head orientation on human postural stability following unilateral vestibular ablation. *J Vestibular Res Equilib Orientat*. 1990;1(2):153-160.

60. Burke TN, Franca FJ, Ferreira de Meneses SR, Cardoso VI, Marques AP. Postural control in elderly persons with osteoporosis: Efficacy of an intervention program to improve balance and muscle strength: A randomized controlled trial. *Am J Phys Med Rehabil*. 2010;89(7):549-556.

61. Kim JY, Kwag KI. Clinical effects of deep cervical flexor muscle activation in patients with chronic neck pain. *Journal of physical therapy science*. 2016;28(1):269.

62. Proske U. What is the role of muscle receptors in proprioception? *Muscle Nerve*. 2005;31(6):780-787.

63. Judge JO, King MB, Whipple R, Clive J, Wolfson LI. Dynamic balance in older persons: Effects of reduced visual and proprioceptive input. *J Gerontol A Biol Sci Med Sci*. 1995;50(5):M263-70.

64. Kofotolis N, Kellis E. Effects of two 4-week proprioceptive neuromuscular facilitation programs on muscle endurance, flexibility, and functional performance in women with chronic low back pain. *Phys Ther*. 2006;86(7):1001-1012.

65. Liu-Ambrose T, Eng JJ, Khan KM, Carter ND, McKay HA. Older women with osteoporosis have increased postural sway and weaker quadriceps strength than counterparts with normal bone mass: Overlooked determinants of fracture risk? *J Gerontol A Biol Sci Med Sci*. 2003;58(9):M862-6.

66. Albrand G, Munoz F, Sornay-Rendu E, DuBoeuf F, Delmas P. Independent predictors of all osteoporosis-related fractures in healthy postmenopausal women: The OFELY study. *Bone*. 2003;32(1):78-85.

67. Herman T, Giladi N, Gurevich T, Hausdorff JM. Gait instability and fractal dynamics of older adults with a "cautious" gait: Why do certain older adults walk fearfully? *Gait Posture*. 2005;21(2):178-185.

68. McDaniel G, Renner JB, Sloane R, Kraus VB. Association of knee and ankle osteoarthritis with physical performance. *Osteoarthritis and Cartilage*. 2011;19(6):634-638.

69. Liu-Ambrose T, Eng JJ, Khan KM, Mallinson A, Carter ND, McKay HA. The influence of back pain on balance and functional mobility in 65- to 75-year-old women with osteoporosis. *Osteoporosis Int*. 2002;13(11):868-873.

70. Francis RM, Aspray TJ, Hide G, Sutcliffe AM, Wilkinson P. Back pain in osteoporotic vertebral fractures. *Osteoporosis Int*. 2008;19(7):895-903.

71. Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY. Increased gait unsteadiness in community-dwelling elderly failers. *Arch Phys Med Rehabil*. 1997;78(3):278-283.

72. Hartikainen S, Lonnroos E, Louhivuori K. Medication as a risk factor for falls: Critical systematic review. *J Gerontol A Biol Sci Med Sci*. 2007;62(10):1172-1181.

73. Liu Y, Chan S.Y. JSY, Yan H. JH. Neuropsychological mechanisms of falls in older adults. *Front Aging Neurosci*. 2014;6(APR).

74. Blake AJ, Morgan K, Bendall MJ, et al. Falls by elderly people at home: Prevalence and associated factors. *Age Ageing*. 1988;17(6):365-372.

75. Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Ageing*. 1990;19(2):136-141.

76. Giangregorio LM, Thabane L, Adachi JD, et al. Build better bones with exercise: Protocol for a feasibility study of a multicenter randomized controlled trial of 12 months of home exercise in women with a vertebral fracture. *Phys Ther*. 2014;94(9):1337-1352.

77. Schousboe JT, Vokes T, Broy SB, et al. Vertebral fracture assessment: The 2007 ISCD official positions. *Journal of Clinical Densitometry*. 2008;11(1):92-108.

78. Meretta BM, Whitney SL, Marchetti GF, Sparto PJ, Muirhead RJ. The five times sit to stand test: Responsiveness to change and concurrent validity in adults undergoing vestibular rehabilitation. *J Vestibular Res Equilib Orientat*. 2006;16(4-5):233-243.

79. Whitney SL, Wrisley DM, Marchetti GF, Gee MA, Redfern MS, Furman JM. Clinical measurement of sit-to-stand performance in people with balance disorders: Validity of data for the five-times-sit-to-stand test. *Phys Ther*. 2005;85(10):1034-1045.

80. Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls: A prospective study. *JAMA*. 1989;261(18):2663-2668.

81. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol*. 1994;49(2):M85-M94.

82. Podsiadlo D, Richardson S. The timed 'up and go': A test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39(2):142-148.

83. Hill KD, Bernhardt J, McGann AM, Maltese D, Berkovits D. A new test of dynamic standing balance for stroke patients: Reliability, validity and comparison with healthy elderly. *Physiotherapy Canada*. 1996;48(4):257-262.

84. Shipp K, Purser J, Gold D, et al. Timed loaded standing: A measure of combined trunk and arm endurance suitable for people with vertebral osteoporosis. *Osteoporosis Int*. 2000;11(11):914-922.

85. Sugalya A. Concurrent validity of occiput-wall distance to measure kyphosis in communities. *Journal of Clinical Trials*. 2012.

86. Cho B-, Scarpace D, Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. *J Am Geriatr Soc*. 2004;52(7):1168-1173.

87. Podsiadlo D, Richardson S. The timed 'up and go': A test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39(2):142-148.

88. Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. *Am J Med*. 1985;78(1):77-81.

89. Goldberg A, Chavis M, Watkins J, Wilson T. The five-times-sit-to-stand test: Validity, reliability and detectable change in older females. *Aging Clin Exp Res*. 2012;24(4):339-344.

90. Steffen TM, Hacker TA, Mollinger L. Age- and gender-related test performance in community-dwelling elderly people: Six-minute walk test, berg balance scale, timed up & go test, and gait speeds. *Phys Ther*. 2002;82(2):128-137.

91. De Pew ZS, Karpman C, Novotny PJ, Benzo RP. Correlations between gait speed, 6-minute walk distance, physical activity, and self-efficacy in patients with severe chronic lung disease. *Respir Care*. 2013;58(12):2113-2119.

92. Haines T, Kuys SS, Morrison G, Clarke J, Bew P, McPhail S. Development and validation of the balance outcome measure for elder rehabilitation. *Arch Phys Med Rehabil*. 2007;88(12):1614-1621.

93. Kuys SS, Morrison G, Bew PG, Clarke J, Haines TP. Further validation of the balance outcome measure for elder rehabilitation. *Arch Phys Med Rehabil*. 2011;92(1):101-105.

94. Bono C, Ried LD, Kimberlin C, Vogel B. Missing data on the center for epidemiologic studies depression scale: A comparison of 4 imputation techniques. *Research in Social and Administrative Pharmacy*. 2007;3(1):1-27.

95. Curran D, Molenberghs G, Fayers P, Machin D. Incomplete quality of life data in randomized trials: Missing forms. *Stat Med*. 1998;17(5-7):697-709.

96. Christine DP, John R. Statistics without maths for psychology using SPSS for windows. . 2002.

97. Sun G, Shook TL, Kay GL. Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. *J Clin Epidemiol*. 1996;49(8):907-916.

98. Van Der Jagt-Willems HC, De Groot MH, Van Campen JPCM, Lamoth CJC, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: A prospective cohort study. *BMC Geriatrics*. 2015;15(1).

99. Schneider DL, von Muhlen D, Barrett-Connor E, Sartoris DJ. Kyphosis does not equal vertebral fractures: The rancho bernardo study. *J Rheumatol*. 2004;31(4):747-752.

100. Takeda N, Kobayashi T, Atsuta Y, Matsuno T, Shirado O, Minami A. Changes in the sagittal spinal alignment of the elderly without vertebral fractures: A minimum 10-year longitudinal study. *Journal of orthopaedic science*. 2009;14(6):748-753.

101. Katzman W, Vittinghoff E, Kado D, Lane N, Ensrud K, Shipp K. Thoracic kyphosis and rate of incident vertebral fractures: The fracture intervention trial. *Osteoporosis Int*. 2016:1-5.

102. Kado DM, Miller-Martinez D, Lui L-, et al. Hyperkyphosis, kyphosis progression, and risk of non-spine fractures in older community dwelling women: The study of osteoporotic fractures (SOF). *J Bone Miner Res*. 2014;29(10):2210-2216.

103. Antonelli-Incalzi R, Pedone C, Cesari M, Di Iorio A, Bandinelli S, Ferrucci L. Relationship between the occiput-wall distance and physical performance in the elderly: A cross sectional study. *Aging Clinical and Experimental Research*. 2007;19(3):207-212.

104. Arnold CM, Faulkner RA. The history of falls and the association of the timed up and go test to falls and near-falls in older adults with hip osteoarthritis. *BMC geriatrics*. 2007;7(1):1.

105. Jonsson E. *Effects of healthy aging on balance: A quantitative analysis of clinical tests.* Institutionen för klinisk neurovetenskap, arbetsterapi och äldrevårdsforskning

(NEUROTEC)/Department of Clinical Neuroscience, Occupational Therapy and Elderly Care Research (NEUROTEC); 2006.

106. Yamashita T, Minaki Y, Oota I, Yokogushi K, Ishii S. Mechanosensitive afferent units in the lumbar intervertebral disc and adjacent muscle. *Spine*. 1993;18(15):2252-2256.

107. Pluijm S, Tromp A, Smit J, Deeg D, Lips P. Consequences of vertebral deformities in older men and women. *Journal of bone and mineral research*. 2000;15(8):1564-1572.

108. Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: A systematic review. *Arch Phys Med Rehabil*. 2014;95(1):129-140.

109. Greendale GA, Huang M-, Karlamangla AS, Seeger L, Crawford S. Yoga decreases kyphosis in senior women and men with adult-onset hyperkyphosis: Results of a randomized controlled trial. *J Am Geriatr Soc*. 2009;57(9):1569-1579.

110. Bautmans I, Van Arken J, Van Mackelenberg M, Mets T. Rehabilitation using manual mobilization for thoracic kyphosis in elderly postmenopausal patients with osteoporosis. *J Rehabil Med*. 2010;42(2):129-135.

111. Katzman WB, Sellmeyer DE, Stewart AL, Wanek L, Hamel KA. Changes in flexed posture, musculoskeletal impairments, and physical performance after group exercise in community-dwelling older women. *Arch Phys Med Rehabil*. 2007;88(2):192-199.

Appendix 1

Form for Radiologist Verification of Vertebral Fracture

Please indicate the presence of deformity, pathology or inadequate film quality for each vertebral level below. When a row is left empty, it will be assumed that the vertebra is normal.

Vertebral Level	Concerns		Deformity consistent with fracture?	Morphology			% Deformity	Comments
	Inadequate film quality	Vertebral pathology		Anterior	Middle	Posterior		
T1	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T2	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T3	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T4	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T5	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T6	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T7	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T8	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T9	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T10	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T11	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
T12	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
L1	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
L2	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
L3	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
L4	☐	☐	☐Y	☐	☐	☐	☐☐.☐	
L5	☐	☐	☐Y	☐	☐	☐	☐☐.☐	

☐ There is no pathology or other reason to exclude the individual from the trial

☐ The absence of the AP view made it difficult to verify the presence or absence of fracture or pathology.

☐ The quality of the film is poor and must be excluded or repeated. Note to site techs.

Appendix 2

<table>
<tr><td colspan="6">Overall Thesis Question: Do fracture characteristics or OWD explain more variance in physical performance measures in women with a suspected vertebral fracture, over the age of 65?</td></tr>
<tr><td colspan="6">Overall Thesis Objective: To explain the variance in physical performance in women with a suspected vertebral fracture over the age of 65 by exploring vertebral fracture characteristics and posture</td></tr>
<tr><td colspan="6">Overall Thesis Hypothesis: I hypothesize that OWD will explain more of the variance in physical performance measures than fracture characteristics.</td></tr>
<tr><td colspan="6">Objective 1: To determine the association between vertebral fracture characteristics (number, severity and location), posture and the Timed Up and Go Test</td></tr>
<tr><td>Questions</td><td>Hypothesis</td><td>Independent Variable</td><td>Dependent Variable</td><td>Covariates</td><td>Statistical Test</td></tr>
<tr><td>Is there an association between vertebral fracture characteristics, posture and Timed Up and Go?</td><td>It is hypothesized that a greater number, greater severity, more mid thoracic vertebral fractures, and a greater OWD will result in slower time on the TUG</td><td>Number of vertebral Fractures
Severity of vertebral fractures
- Grade 1-0, Grade 2, at least one Grade 3
Location 1: T4-8;
Location 2: T9-L1;
Location 3: L2-5
OWD</td><td>TUG</td><td>Age
Oral glucocorticoid use
Pain at Rest
Pain during Movement</td><td>Multivariable variable regression (p<0.05)</td></tr>
</table>

Objective 2: To determine the association between vertebral fracture characteristics (number, severity and location), posture and other selected physical performance measures

Question	Hypothesis	Independent Variable	Dependent Variable	Covariates	Statistical Test
Is there an association between vertebral fracture characteristics, OWD and other selected physical performance measures?	Longer time on 5 x sit to stand with increasing OWD, greater number of fractures, worse severity and mid-thoracic fractures Longer time on 4 m walk with increasing OWD, greater number of fractures, worse severity and mid-thoracic fractures There will be less steps on the step test with an increasing OWD, greater number of fractures, worse severity and mid-thoracic fractures Shorter time on timed loaded standing with increasing OWD, greater number of fractures, worse severity and mid-thoracic fractures.	Number of vertebral fractures Severity of vertebral fractures - Grade 1-0, Grade 2, at least one Grade 3 Location 1: T4-8; Location 2: T9-L1; Location 3: L2-5 OWD	5 x sit to stand 4 m walk Step test Timed loaded standing	Age Oral glucocorticoid use Pain at Rest Pain during Movement	Multivariable regression $p < 0.05$

Objective 3: To determine the association between vertebral fracture characteristics and posture

Question	**Hypothesis**	**Independent Variable**	**Dependent Variable**	**Covariates**	**Statistical Test**
Do vertebral fracture characteristics explain the variance in posture?	It is hypothesized that a greater number, greater severity and more mid-thoracic vertebral fractures will be associated with an increased OWD	Number of vertebral Fractures Severity of vertebral fractures - Grade 1-0, Grade 2, at least one Grade 3 Location 1: T4-8; Location 2: T9-L1; Location 3: L2-5	OWD	Age Oral glucocorticoid use Pain at Rest Pain during Movement	Multivariable regression $p < 0.05$

Table 2: Descriptive Participant Information

	N	Mean	Stdv
Age (years)	158	75.9	6.52
Height (cm)	158	156.4	7.11
Weight (kg)	158	65.4	14.06
BMI	158	26.7	5.31
OWD (cm)	158	5.7	4.62
Fracture Number	158	2.2	1.81
Number of Comorbidities	158	2.5	2.37
Number of Medications/ Supplements	158	5.3	3.89
Number of Fractures	158	2.2	1.81
No Fractures (n)	13		
Severity of Fractures (N)	158		
Grade 0-1 (n)	16		
Grade 2 (n)	47		
Grade 3 (n)	95		
Location of Fractures (N)	158		
T1-T3	4		
T4-T8 (n)	65		
T9-L1 (n)	107		
L2-L5 (n)	57		

OWD = Occiput-to-Wall Distance; BMI= Body Mass Index

Table 3: Descriptive statistics of physical performance assessments comparing all participants, those that report 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		
	n	Mean	Stdv	n	Mean	Stdv	n	Mean	Stdv
Five Times Sit-to-Stand (seconds)	137	15.27	5.78	101	14.37	5.78	35	17.93	5.12
Imputed Five Times Sit-to-Stand (seconds)	158	15.6	6.41	108	14.3	5.61	49	18.73	6.79
4m Walk (seconds)	158	4.2	1.27	108	3.81	0.87	49	5.24	1.35
Step Test (number of steps)	158	11.8	4.16	108	13.05	3.77	48	9.52	3.31
TUG (seconds)	158	11.9	3.97	108	10.56	2.78	49	15.23	4.04
Timed Loaded Standing (seconds)	38	82.4	44.51	27	82.83	47.35	10	77.51	38.55

TUG= Time Up and Go Test

Table 4: Correlation of fracture characteristics, and confounding variables with OWD. Pearson's correlation was used for all variables except the location variables. Spearman's Correlation was used for the location variables

	OWD
Number of Fracture	0.29**
T4-T8	0.1
T9-L1	0.17*
L2-L5	0.16*
Severity of Fracture	0.24**
Age	-0.07
Pain during Movement	0.21**

*p<0.05; **P<0.01

Table 5:Unadjusted variance in occiput-to-wall distance, multivariable regression

	Unadjusted				
	Unstandardized B (Standard Error)	Standardized B	95% Confidence Interval	p value	R Squared
Number of Fracture	0.82 (0.39)	.320	0.04-1.59	0.04	
Severity of Fracture	0.83 (0.53)	.165	-0.22-1.88	0.12	
T4-T8	-1.14 (1.14)	-.121	-3.39-1.10	0.32	
T9-L1	-0.64 (1.24)	-.066	-3.08-1.80	0.61	
L2-L5	-0.48 (1.15)	-.049	-2.75-1.79	0.68	
Model				0.01	0.10

Table 6: Adjusted multivariable regression analyses in occiput-to-wall distance , with and without including interaction terms in the model

	Adjusted				Adjusted and Interaction Terms			
	Unstandardized B	95% Confidence Interval	p value	R Squared	Unstandardized B	95% Confidence Interval	p value	R Squared
Number of Fracture	0.71	(-0.06, 1.49)	0.07		-1.24	(-4.33, 1.85)	0.43	
Severity of Fracture	1.08	(0.01, 2.15)	0.05		0.26	(-1.42, 1.94)	0.76	
T4-T8	-1.06	(-3.28, 1.16)	0.35		0.81	(-2.53, 4.15)	0.63	
T9-L1	-0.71	(-3.13, 1.71)	0.56		0.05	(-3.96, 4.06)	0.98	
L2-L5	-0.57	(-2.82, 1.68)	0.62		0.37	(-2.99, 3.72)	0.83	
Age	-0.02	(-0.13, 0.09)	0.69		0.00	(-0.12, 0.11)	0.96	

Pain during Movement	0.30	(0.04, 0.56)	0.03		0.28	(0.02, 0.55)	0.04	
Number x Severity					0.91	(-0.22, 2.04)	0.11	
Number x T4-T8					-0.74	(-1.81, 0.33)	0.17	
Number x T9-L1					-0.10	(-2.21, 2.02)	0.93	
Number x L2-L5					-0.31	(-1.37, 0.75)	0.57	
Model			0.02	0.14			0.006	0.16

Table 7: Correlation of fracture characteristics, posture and confounding variables with the TUG test. Pearson's correlation was used for all variables except the location variables. Spearman's Correlation was used for the location variables

	Timed Up and Go Correlations
Number of Fracture	0.16*
T4-T8	0.06
T9-L1	0.11
L2-L5	0.17*
Severity of Fracture	0.16*
OWD	0.37**

Age	0.03
Pain during Movement	0.23**

*p<0.05
**P<0.01

Table 8: Unadjusted variance in Timed Up and Go Test, multivariable regression Analysis

	Unstandardized B	95% Confidence Interval (lower limit, upper limit)	p value	R Squared
Number of Fracture	-0.04	(-0.68, 0.60)	0.90	
Severity of Fracture	0.27	(-0.59, 1.14)	0.53	
T4-T8	-0.19	(-2.03, 1.64)	0.83	
T9-L1	0.06	(-1.93, 2.06)	0.95	
L2-L5	0.64	(-1.22, 2.50)	0.50	
OWD	0.29	(0.16, 0.42)	<0.001	
Model			<0.001	0.149

Table 9: Adjusted multivariable regression analyses in Timed Up and Go test, with and without including interaction terms in the model

	Adjusted				Adjusted with Interactions			
	Unstandardized B	95% Confidence Interval (lower limit, upper limit	p value	R Squared	Unstandardized B	95% Confidence Interval (lower limit, upper limit	p value	R Squared
Number of Fracture	-0.09	(-0.72, 0.54)	0.79		0.14	(-2.38, 2.65)	0.91	
Severity of Fracture	0.53	(-0.34, 1.41)	0.23		0.25	(-1.11, 1.61)	0.72	
T4-T8	-0.15	(-1.95, 1.65)	0.87		0.29	(-2.43, 2.99)	0.83	
T9-L1	-0.08	(-2.03, 1.87)	0.94		-0.22	(-3.48, 3.03)	0.89	
L2-L5	0.52	(-1.30, 2.34)	0.58		1.97	(-0.75, 4.69)	0.16	
OWD	0.25	(0.12, 0.38)	<0.001		0.24	(0.11, 0.38)	<0.001	
Age	0.03	(-0.06, 0.12)	0.55		0.03	(-0.06, 0.12)	0.56	
Pain during movement	0.32	(0.10, 0.53)	<0.001		0.34	(0.12, 0.56)	0.003	
Number x Severity					0.06	(-0.86, 0.99)	0.89	
Number x T4-T8					-0.24	(-1.11, 0.64)	0.59	
Number x T9-L1					0.23	(-1.49, 1.94)	0.79	
Number x L2-L5					-0.65	(0.21, 0.10)	0.14	
Model			<0.001	0.2			<0.001	0.22

Table 10: Association of fracture characteristics, posture and confounding variables with the selected physical performance test. Pearson's correlation was used for all variables except the location variable, where Spearman's Correlation was used.

	Five Time Sit to Stand	Four Meter Walk	Step Test	Timed Loaded Standing
Number of Fracture	0.12	0.17*	-0.1	-0.23
T4-T8	-0.07	0.04	0.02	-0.28*
T9-L1	0.12	0.07	-0.12	0.06
L2-L5	0.21**	0.12	-0.09	-0.29*
Severity of Fracture	0.09	0.22**	-0.05	-0.12
OWD	0.27**	0.38**	-0.41**	-0.22
Age	0.01	0.02	0.03	0.05
Pain during Movement	0.13	0.32**	-0.22**	-0.54**

*p<0.05; **P<0.01

Table 11: Unadjusted variance in Five Times Sit-to-Stand test, Four-meter walk test, Step test and Timed Loaded Standing test, multivariable regression

Five Times Sit to Stand Test

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	-0.11	-1.16, 0.95	0.84	
Severity of Fracture	-0.11	-1.52. 1.31	0.88	
T4-T8	-1.58	-4.60, 1.44	0.30	
T9-L1	0.66	-2.61, 3.94	0.69	
L2-L5	2.93	-0.12, 5.98	0.06	
OWD	0.33	0.12, 0.55	0.002	
Model			<0.001	0.13

Four-meter Walk Test

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	0.14	-0.06, 0.34	0.18	
Severity of Fracture	0.30	0.03, 0.57	0.03	
T4-T8	-0.49	-1.07, 0.08	0.09	

T9-L1	-0.46	-1.09, 0.16	0.14	
L2-L5	-0.36	-0.94, 0.22	0.22	
OWD	0.09	0.05, 0.13	<0.001	
Model			<0.001	0.18

Step Test

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	0.10	-0.56, 0.76	0.77	
Severity of Fracture	0.41	-0.48, 1.30	0.36	
T4-T8	0.00	-1.89, 1.90	>0.99	
T9-L1	-0.95	-3.00, 1.10	0.36	
L2-L5	-0.56	-2.47, 1.35	0.57	
OWD	-0.36	-0.50, -0.23	<0.001	
Model			<0.001	0.18

Timed Loaded Standing Test*

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared

Severity of Fracture	7.61	(-13.04, 28.25)	0.46	
T4-T8	-30.03	(-65.52, 5.46)	0.09	
T9-L1	1.56	(-37.20, 40.31)	0.94	
L2-L5	-27.71	(-62.25, 6.84)	0.11	
OWD	-2.19	(5.23, 0.85)	0.15	
Model			0.15	0.22

*note the timed loaded standing test had n=38

Table 12: Adjusted multivariable regression analyses in Five Times Sit-to-Stand test, Four-meter walk test, Step test and Timed Loaded Standing test , with and without including interaction terms in the model

	Adjusted				Adjusted with Interactions			
	Five Times Sit to Stand							
	Unstandardized B (Standard Error)	95% Confidence Interval (lower limit, upper limit)	p value	R Squared	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	-0.18	-1.22, 0.86	0.73		0.35	(-3.79, 4.50)	0.87	
Severity of Fracture	0.34	-1.10, 1.78	0.64		0.23	(-2.02, 2.48)	0.84	
T4-T8	-1.48	-4.45, 1.49	0.36		-0.74	(-5.20,	0.75	

						3.74)		
T9-L1	0.62	-2.60, 3.85	0.70		-0.38	(-5.74, 4.98)	0.89	
L2-L5	2.84	-0.16, 5.84	0.06		4.67	(0.18, 9.16)	>0.999	
OWD (cm)	0.29	0.07, 0.50	0.01		0.28	(0.06, 0.50)	0.01	
Age (years)	0.03	-0.12, 0.17	0.70		0.03	(-0.12, 0.19)	0.66	
Pain during movement	0.32	-0.03, 0.68	0.07		0.33	(-0.03, 0.69)	0.07	
Number x Severity					-0.12	(-1.65, 1.40)	0.87	
Number x T4-T8					-0.40	(-1.84, 1.04)	0.58	
Number x T9-L1					0.77	(-2.06, 3.60)	0.59	
Number x L2-L5					-0.85	(-2.27, -0.57)	0.24	
Model			0.001	0.16			0.005	0.18

Four-meter Walk

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	0.12	(0.43, 4.88)	0.23		0.55	(-0.24, 1.33)	0.17	
Severity of Fracture	0.37	(0.10, 0.64)	0.01		0.23	(-0.19, 0.66)	0.28	

T4-T8	-0.48	(-1.05, 0.08)	0.09		-0.39	(-1.23, 0.46)	0.37	
T9-L1	-0.51	(-1.12, 0.10)	0.10		-0.16	(-1.17, 0,86)	0.76	
L2-L5	-0.41	(-0.98, 0.16)	0.16		-0.28	(-1.12, 0.57)	0.52	
OWD	0.08	(0.03, 0.12)	<0.001		0.08	(0.03, 0.12)	<0.001	
Age	0.003	(-0.02, 0.03)	0.82		0.00	(-0.03, 0.03)	0.98	
Pain during Movement	0.11	(0.04, 0.18)	0.001		0.12	(0.05, 0.19)	<0.001	
Number x Severity					-0.02	(-0.31, 0.26)	0.88	
Number x T4-T8					-0.07	(-0.34, 0.20)	0.60	
Number x T9-L1					-0.26	(-0.79, 0.28)	0.35	
Number x L2-L5					-0.07	(-0.34, 1.9)	0.59	
Model			<0.001	0.24			<0.001	0.25
Step Test								
	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Number of Fracture	0.15	(-0.51, 0.80)	0.66		-0.49	(-3.11, 2.13)	0.71	
Severity of Fracture	0.28	-0.63, 1.12)	0.54		0.67	(-0.75, 2.09)	0.35	
T4-T8	0.00	(-1.87, 1.87)	>0.99		0.37	(-2.46,	0.80	

						3.19)		
T9-L1	-0.82	-2.91-1.29	0.43		-2.00	(-5.39, 1.38)	0.24	
L2-L5	-0.42	(-2.31, 1.47)	0.66		-0.92	(-3.75, 1.92)	0.52	
OWD	-0.33	(-0.47, -0.19)	<0.001		-0.33	(-0.47, -0.19)	<0.001	
Age	0.01	(-0.08, 0.10)	0.81		0.02	(-0.08, 0.12)	0.68	
Pain during Movement	-0.29	(-0.51, -0.07)	0.01		-0.31	(-0.54, -0.08)	0.01	
Number x Severity					-0.08	(-1.05, 0.88)	0.86	
Number x T4-T8					-0.11	(-1.03, 0.80)	0.80	
Number x T9-L1					0.83	(-0.96, 2.62)	0.36	
Number x L2-L5					0.22	(-0.68, 1.12)	0.63	
Model			<0.001	0.21			<0.001	0.22

Timed Loaded Standing*

	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared	Unstandardized B (Standard Error)	95% Confidence Interval	p value	R Squared
Severity of Fracture	3.58	(-19.64, 26.80)	0.75		5.40	(-27.80, 38.59)	0.74	
T4-T8	-27.26	(-64.31, 9.79)	0.14		-105.38	(-175.53, -35.24)	<0.001	
T9-L1	11.19	(-31.14, 53.51)	0.59		-12.45	(-92.22, 67.32)	0.75	
L2-L5	-20.90	(-57.61, 15.81)	0.25		24.04	(-49.85, 97.93)	0.51	

OWD	-1.56	(-4.81, 1.69)	0.33		-0.74	(-3.80, 2.31)	0.62	
Age	0.07	(-2.22, 2.37)	0.95		-0.51	(-2.63, 1.61)	0.62	
Pain during Movement	-4.48	(-11.25, 2.29)	0.19		-7.83	(-14.49, -1.16)	0.02	
Number x Severity					-2.21	(-15.74, 11.31)	0.74	
Number x T4-T8					25.31	(5.43, 45.19)	0.01	
Number x T9-L1					11.69	(-21.32, 44.69)	0.47	
Number x L2-L5					-21.43	(-43.07, 0.22)	0.05	
Model			0.21	0.27			0.04	0.56

Table 13: Pearson's R Correlation of the Selected Physical Performance Assessments

	Five Times Sit-to-Stand	Four-meter Walk	Step Test	Timed Up and Go	Timed Loaded Standing
Five Times Sit-to-Stand	--	0.524**	-0.452**	0.767**	0.23
Four-meter Walk		--	-0.417**	0.762**	-0.09
Step Test			--	-0.541**	0.09
Timed Up and Go				--	-0.05
Timed Loaded Standing					--

*p<0.05

** P<0.01