BALANCE SCREENING FOR FALL RISK ASSESSMENT IN COPD

VALIDATING SHORT BALANCE SCREENING TESTS FOR ASSESSING FALL RISK IN PEOPLE WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD)

BY

RACHEL GABRIELLE MCLAY, H.B.SC

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Abstract

Background: People with COPD have significant balance impairments and an increased risk of falls. The psychometric properties of short balance screening tests to inform fall risk assessment in COPD have not been studied. The objective of this study was to compare the validity of four short balance tests suitable for fall risk screening to identify the most optimal screening tool(s).

Methods: Participants ≥ 60 years with COPD attended a single physical assessment with completion of questionnaires. Correlation coefficients were used to describe relationships between the Brief Balance Evaluation Systems Test (Brief BESTest), Single-Leg Stance (SLS), Timed Up and Go (TUG) and Timed Up and Go Dual-Task (TUG-DT) tests, and other measures of balance, measures of muscle strength, exercise tolerance, functional limitation, disability and prognosis. Independent *t*-tests or Mann-Whitney *U* tests were used to examine differences between groups with respect to fall risk. Receiver operating characteristic curves were plotted to examine the ability to of the screening tests to identify individuals with previous falls.

Results: Seventy-three participants with COPD completed the study (age 73.0 ± 6.9 years; FEV_1 47.0 ± 19.8% predicted). All balance screening tests demonstrated moderate to strong correlations with the Berg Balance Scale (r= 0.47 to 0.80, p<0.05) and Activities-specific Balance Confidence scale (r= 0.44 to 0.61, p<0.05). The Brief BESTest and SLS showed the strongest correlations with other balance measures and demonstrated the most consistent ability to discriminate between fall risk groups. The

Brief BESTest was the only screening test that identified individuals who reported a previous fall with acceptable accuracy (AUC= 0.7).

Conclusions: The Brief BESTest and SLS show the most promise as balance screening tools for fall risk assessment in older adults with COPD. These results will need to be prospectively confirmed with a larger sample size.

Keywords: Balance, Falls, COPD

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Introduction

1.1 Summary of Problem

Chronic obstructive pulmonary disease (COPD) is a progressive respiratory disease that is characterized by irreversible airflow limitation[1] that represents a significant impact in Canada as a leading cause of disability, hospitalization and mortality.[2-4] It is now estimated to rank as the third leading cause of death worldwide.[5] Research over the past decade has established that COPD is a complex, multisystem disease with detrimental effects that extend past respiratory function to exercise performance, muscle function, mobility and mental health.[6-15] In particular, a growing body of evidence has identified significant balance impairments[16-27] and an increased risk of falls[16,20,28-34] to be important secondary effects independent from aging in COPD.

Balance control is an essential skill that is required to maintain functional independence, to facilitate mobility and to avoid falls.[35] In line with previous research on balance and falls in older adults,[36-38] a number of studies to date have demonstrated a relationship between marked balance deficits and a higher fall risk in COPD.[16,19,20,24,25,30] People with COPD have reported a prevalence of falls up to 51%[16,20,24,25,30,33] compared to 33% in the general older population[39-42] and an annual fall rate up to six times higher than expected for their age based on prospective data.[34] Furthermore, an analysis of 16,000 older adults

≥ 65 years old in Canada found that COPD was the only chronic condition to predict falls.[29]

Given that balance impairment is a leading modifiable risk factor for falls,[43] and the overwhelming impact of falls on the individual and healthcare system,[44] timely and tailored approaches to fall risk assessment and prevention are needed for persons with COPD. Current best practice guidelines for fall prevention in older adults highlight balance screening as a key component of fall risk assessment and prevention.[43,45,46] The American Thoracic Society/European Respiratory Society (ATS/ERS) have recently updated pulmonary rehabilitation guidelines to recommend balance testing as part of an outcomes assessment.[47] However, the optimal test for balance screening in COPD has yet to be specified and moreover, little research has been conducted on the psychometric properties of balance screening tests in COPD. Therefore, the objective of this thesis is to determine the validity of clinically feasible balance screening tests for fall risk assessment in COPD. Overall, this research aims to identify the optimal balance screening test to use in clinical practice to guide fall risk identification and management strategies in COPD.

1.2 Literature Review

This thesis has incorporated literature common to respiratory health, rehabilitation and geriatrics. The following review is divided into three major sections: 1) Background on COPD; 2) Balance and Falls in Older Adults; and 3) Balance and Falls in Older Adults with COPD.

1.2.1 Background on COPD

1.2.1.1 COPD: Definition and Impact

COPD can be defined as a widespread yet preventable and manageable respiratory disease involving persistent, progressive and irreversible airflow limitation as a result of airway, alveolar and/or microvasculature damage.[48-51] This damage is caused by long-term exposure to noxious particles or gases,[48,50,51] where cigarette smoking is the most concerning risk factor for COPD worldwide.[52] According to the Global Burden Disease Study, COPD is the third leading cause of death for both sexes and responsible for approximately 3.2 million deaths a year worldwide.[5] However, the global prevalence may be underestimated due to under-diagnosis in younger patients, males, persons with a lower education level, persons who smoke and who have never smoked, persons at milder stages of the disease, patients who are missing previous spirometry and discrepancies in respiratory symptom reporting.[53] A recent report from the Canadian Chronic Disease Surveillance System stated that 2 million people > 35 years were living with COPD in Canada between 2011 and 2012, where the highest prevalence of COPD was observed in individuals ≥ 85 years.[54] This is no surprise as the prevalence of COPD increases across the lifespan, with a higher prevalence in men beyond 65 years.[54]

Diagnosis of COPD is based on abnormal lung function determined by spirometry results (traditionally a post-bronchodilator FEV_1/FVC ratio of less than 0.70), as this is the most widely accessible and reproducible test of lung function available.[48,50,51] Diagnosis is also based on the presentation of symptoms including chronic cough and/or sputum production, dyspnea, or recurrent lower respiratory infections.[55] Cigarette smoking is the main risk factor for the development of COPD worldwide,[51,52,56] however exposure to environmental or occupational pollutants may also contribute.[51] COPD is diagnosed in individuals ≥ 35 years, although it may not become clinically apparent until even later in life due to its progressive nature.[54] The severity of COPD is on a spectrum categorized into three main stages including mild, moderate and severe.[48]

1.2.1.2 COPD: Secondary Effects

Although it primarily affects lung function and breathing, COPD is an extensively disabling disease with numerous secondary consequences on distant systems and functions of the body.[6,7] To date, it is understood that in addition to respiratory impairment, COPD also has a negative impact on muscle function,[8,9,57-60] exercise performance,[6,61] mobility,[62,63] psychological disorders (anxiety and depression),[12-15,64] cardiovascular disease (coronary artery disease),[48] metabolic disorders (osteoporosis),[48] and based on more recent research, postural control and fall risk.[16-33]

In a cross-sectional analysis of the Function, Living, Outcomes and Work (FLOW) study, 1202 COPD patients (mean age 58 years; 57% female) were compared to 302 age-matched healthy controls, and it was determined that poor lower extremity functioning, worsened exercise performance, skeletal muscle weakness and a greater risk of self-reported functional limitation were directly related to COPD after having controlled for age, sex, height, race, smoking history and education.[6] In relation to these functional limitations, substantial balance deficits have been observed in people with COPD[16-27] and have demonstrated an association with a greater fall risk in this population.[16,19,20,24,25,30] These deficits in balance confirmed by various research studies have also been recognized by international guidelines in pulmonary rehabilitation.[47] The most recent ATS/ERS statement on pulmonary rehabilitation has recommended including a balance assessment in their scope of outcomes for people with COPD. Although this is an important first step, there is a need for further guidance on test selection and interpretation in this population.

1.2.1.3 COPD: How is it Managed?

Overall, the effective management of COPD involves assessing and monitoring the disease, minimizing risk factors for disease development and progression (inhaling first- or second-hand tobacco smoke, indoor/outdoor air pollution or occupational contaminants), managing stable COPD and preventing and treating exacerbations.[1,48] The diagnosis and progression of COPD is evaluated using spirometry.[1,48] In terms of risk factor reduction, smoking cessation is often the first method implemented as it is the most effective way to combat disease progression, symptoms and exacerbations.[1,48,49] In addition to this, pharmacotherapy is often used in the beginning stages of management to improve symptoms, quality of life, exercise tolerance and exacerbation frequency and severity.[1,48,49] Pulmonary rehabilitation is a core component of the management of stable COPD that helps improve symptoms, increase exercise capacity and improve quality of life in patients through exercise training, education, behavioural change promotion and self-management in patients with COPD.[1,47-49] Long-term oxygen therapy is another treatment option for stable COPD (specifically for those with resting hypoxia), as well as ventilatory support (for severe COPD patients) and surgical intervention (lung volume reduction, bronchoscopic interventions or lung transplant for advanced COPD).[48,49] A more recently recognized, but centrally important role in the management of COPD includes the treatment of comorbidities (where COPD is consistently the primary chronic condition and others are coexisting) or multimorbidity (where COPD coexists or overlaps with other chronic conditions without one being primary and the importance of each may vary over time).[18,49,65,66] There has yet to be a method of treatment or management that can reverse the chronic damage to lung function in those with COPD.[48]

1.2.1.4 Pulmonary Rehabilitation

Pulmonary rehabilitation, a cost-effective and beneficial treatment approach for COPD,[47-49] is a comprehensive and targeted intervention that typically incorporates therapies such as supervised exercise training, disease-specific education, behavior change and self-management, nutritional guidance, and social and psychological support.[47] Pulmonary rehabilitation is delivered by an interdisciplinary team including physicians, physiotherapists, nursing and other allied health care professionals, and the individualized program is adjusted to the severity, complexity and comorbid conditions of the patient's diagnosis.[47] The program can be started at any stage of the disease, whether stable or right after an exacerbation.[47] Pulmonary rehabilitation aims to minimize symptom burden, maximize exercise capacity, promote autonomy and participation in daily activities, increase health-related quality of life and achieve long-lasting health behavior changes.[47]

There is ample evidence to support that pulmonary rehabilitation reduces dyspnea, increases exercise tolerance and improves health-related quality of life in people with COPD.[47,49,67]

1.2.2 Balance and Falls in Older Adults

1.2.2.1 Falls in Older Adults

As the aging population continues to rise,[68] falls remain an overwhelming and deadly crisis among older adults.[39,69-71] A recent report from the Canadian Institute for Health Information found that unintentional falls are the number one cause of injury-related hospitalizations across the country.[71] The data shows 152,504 injury hospitalizations as a result of unintentional falls from 2016 to 2017, and of these, a striking 131,994 were older adults ≥ 65 years with the majority between 65 and 84 years old.[71] The average length of a hospital stay after a fall was reported to be just over two weeks and direct costs associated with falls in Canadian older adults are estimated to be over $2 billion.[72]

A fall in an older adult can result in hospitalizations due to serious injury (hip fractures and chronic pain) and can increase the risk of mobility impairment, loss of independence, disability, hospital readmission, social isolation, mortality and morbidity.[35,39,69,70] Previous research has also linked falls to mental health-related consequences including anxiety, depression, loneliness and the development of fear of falling.[69,73-75] Fear of falling has been associated with a higher risk of future falls in addition to diminished self-efficacy and self-confidence, decreased activity participation, reduced quality of life and increased admission to long-term care.[69,73-75] Fear of falling has been previously defined as "low perceived self-efficacy or confidence at avoiding falls"[76,77] or persistent concern about falling,[12,77] and is commonly assessed in community-dwelling older adults using measures of self-efficacy (Falls Efficacy Scale) or balance confidence [Activities-specific Balance Confidence scale (ABC scale)].[73]

Often falls occur due to an accumulation and complex interaction of many risk factors that override an individual's ability to maintain or recover balance.[39,69,70,78] Intrinsic risk factors pertain to the human body and include acute illness, advanced age, balance and/or gait deficits, chronic conditions and disabilities, cognitive impairments or dementia, muscle weakness, medications and poor vision.[39,43,69,78] Extrinsic risk factors relate to the physical environment and an active lifestyle.[69] These may include environmental hazards or dangerous activities such as inadequate lighting, walking on icy sidewalks, or impulsiveness.[43,69,78] Although various intrinsic and extrinsic risk factors can be modified, balance deficits have emerged as one of the more critical modifiable risk factors for falls in older adults.[43,79-82]

1.2.2.2 Balance

Our postural control system consists of two main components: postural orientation (the ability to orient the body to the environment and orient body segments with respect to one another) and postural equilibrium, or balance (the body's ability to maintain center of mass within the limits of the base of support during static or dynamic movement).[37,83,84]

The postural control system functionally operates on the basis of complex sensorimotor system integration (sensory systems, central and peripheral nervous system and musculoskeletal system).[85]

Balance itself can be divided into static equilibrium (the body is balanced to minimize movement and maintain a stance) and dynamic equilibrium (the body is balanced to allow for controlled movement).[37,83] Although both are essential to maintain balance and avoid falls,[86] dynamic adjustments are key in preparing and executing voluntary movement, as well as responding to sudden and unpredictable perturbations that can lead to a fall.[83,86] Change-in-support reactions are an important means for responding to unexpected perturbations. Compensatory stepping (taking a step to avoid a fall) or reaching responses (reaching to grasp a railing to avoid a fall) are both change-in-support reactions critical to dynamic postural control and preventing falls.[36]

As we age, our postural control system is negatively impacted[87,88] and we begin to observe declines in balance attributable to changes in sensory systems (decreased acuity, depth perception, contrast sensitivity and dark adaptation), the central nervous system (cerebral metabolism deficits, loss of neurons, loss of dendrites and less branching, cerebral perfusion deficits and alterations in transmitter metabolism) and the musculoskeletal system (muscle weakness).[85] A narrative review previously published by our research team (please refer to Appendix A) identified important age-related changes in muscle strength and the relationship to responses to external perturbations.[89] Deficits in contractile properties, reduced muscle activation and ability to produce muscle force, a loss of muscle mass, reduced muscle power, fatigability and decreases in specific tension are linked to a poor ability to control lateral stability during stepping reactions and to produce rapid reaching reactions.[89]

Furthermore, there is an abundance of evidence on age-related declines in dual-task performance.[90-94] Dual-task testing is used to assess the ability of an individual to complete two tasks at once- something we often find ourselves doing during daily activities (e.g. walking and talking).[90] It typically involves splitting the individual's attention between a motor task and cognitive challenge.[95] Dual-tasking has been shown to negatively affect balance performance in both younger and older adults using both laboratory and clinical measures of balance.[91,92] This is a result of both tasks competing for attentional resources and information-processing neural pathways and may lead to poor performance in either task or both, referred to as cognitive-motor interference.[96-98] It is more pronounced in older adults as they experience both balance/mobility and cognitive impairments with advanced aging.[87,93,99]

The above age-related changes in our postural control system contribute to an increased risk of falling among older adults.[36,85,91,92,95,100-105] This reinforces the value of including a single or dual-task balance screening test in fall risk assessments for older adults.

1.2.2.3 Fall Prevention

Falls are not only a major threat to the physical and psychological well-being of older adults, but they also have negative consequences on family, friends, caregivers and the healthcare system.[39,44,71] In light of the high economic and personal cost of falling, it is important to identify individuals at highest risk of falling so that effective risk reduction and fall prevention strategies can be carried out. Best practice recommendations for fall prevention in community-dwelling older adults and specific clinical populations have been developed by several major organizations. These include the American Geriatrics Society/British Geriatrics Society (AGS/BGS),[43] the Centers for Disease Control's (CDC) Stopping Elderly Accidents, Deaths & Injuries[106] and the United Kingdom's National Institute for Health Care Excellence (NICE).[46] All of these clinical practice guidelines suggest similar fall prevention algorithms, with the first step recommending that health care providers screen all older patients they encounter for a history of falls and/or concerns about balance.[43,46,106,107] While those who screen negative or "low-risk" simply receive education on falls, those who say yes to either of the screening questions are given a short balance test to determine their risk of falls.[43,46,106,107] If performance is better than a pre-determined cut-off score on the balance screening test, the patient receives education and referral to community-based exercise programs as they are considered "low-risk."[43,46,106,107] Conversely, if they perform worse than the cut-off score on the screening test, their balance is considered impaired and they are referred for a more comprehensive balance assessment as well as a multifactorial fall risk assessment.[43,46,106,107] This information is then used to inform a targeted fall prevention intervention for the high risk patients.[43,46,106,107] Fall prevention exercise programs with balance-specific exercise have been shown to reduce both the rate and risk of falls by up to 40%.[108,109]

Balance testing is recognized as a key component of all clinical practice guidelines for fall risk assessment and prevention in older adults.[43,46,106] However, in order to properly implement this key component of evidence-based guidelines, it is critical that the balance screening tools have established psychometric properties specific to the population they are used in. In addition, although a number of different balance tests have been developed for use in older adults, for screening purposes, it is important to identify tests that are quick to administer and have good predictive validity for falls.[107]

1.2.2.4 Balance Screening Tests for Fall Risk Assessment in Older Adults

There is currently no gold standard balance screening test for fall risk assessment. As a result, this thesis will focus on four main balance screening tests that are either commonly used and suggested for fall risk screening in older adults, or that show promise as a fall risk screening test based on preliminary evidence for their psychometric properties. These include: the Timed Up and Go (TUG),[110] the Timed Up and Go Dual-Task (TUG-DT), the Single-Leg Stance test (SLS) and Brief Balance Evaluation Systems Test (Brief BESTest).[111] All of the tests take 10 minutes or less to administer.[107,112-116]

The TUG is most frequently recommended as a balance screening test for older adults and has been specifically identified as a potential fall risk screening tool by the CDC and AGS/BGS fall prevention algorithms.[43,106] The TUG is a measure of balance and mobility in older adults. The test is scored by recording the timed performance for a person to stand up from a chair, walk 3 metres, turn 180 degrees, return to the chair and sit down at their usual walking pace, with a gait permitted if needed.[110] It takes approximately five minutes to administer[107,112,113] and a longer time is indicative of worse balance/mobility. In regard to measurement properties, the TUG score has demonstrated excellent inter-rater (ICC 0.93 to 0.99) and intra-rater reliability (0.75 to 0.99)[110,112,113,117] as well as good content[110] and convergent (r= 0.47 to 0.92)[110,112,117-119] validity with more extensive tests of balance, tests of balance confidence, mobility and functional capacity in community-dwelling older adults with and without mild cognitive impairment. The TUG score has discriminated between community-dwelling elderly with and without a history of falls[117,120-123] and has generally demonstrated a positive association with falls history in the elderly.[90,124] Although the TUG score has shown some association with future falls in older adults,[113,124,125] it has limited predictive ability[122,123,126] and diagnostic accuracy in community-dwelling and institutionalized older adults with and without cognitive impairment.[118,122,124,126-128]

Another version of the TUG, TUG-DT, is not currently endorsed by fall prevention guidelines but assesses the impact of dual-task performance on balance/mobility using an added secondary cognitive task.[102] The patient is given the same instructions as in the

TUG, but they are also asked to count backwards by threes during the task. As a result, the TUG-DT (sometimes referred to as "TUG cognitive"[120]) is commonly used to examine the relationship between balance/mobility, fall risk and cognitive impairment in older adults.[91] With a similar protocol to the TUG, it also takes approximately five minutes to administer[107,112,113] and a longer time is indicative of worse balance/mobility. Similar to the TUG, this test has the potential to be applied as a fall risk screening tool in older adults as it is a measure of not one, but two risk factors for falls in this population and therefore may offer an even more precise estimate of fall risk.[91,102] As previously discussed, evidence has shown age-related declines in dual-task balance performance with a concurrent cognitive task[91-94] which has been linked to an increased risk of falls in older adults.[94,100,101] As a result of these findings, we are now seeing an emergence of research on the role of dual-task balance tests in assessing fall risk and predicting falls in the elderly.[91,92,95,102,129] In terms of measurement properties, the TUG-DT score has demonstrated convergent validity with more extensive tests of balance (r= 0.66) and excellent intra-rater (ICC= 0.94 to 0.98) and inter-rater reliability (ICC= 0.99) in community-dwelling older adults.[119,120,129,130] The predictive validity of TUG-DT score for falls in older adults is still being investigated,[91,102,131] but there is some support shown from previous work on its discriminant ability. One small cross-sectional study (n= 30) found that TUG-DT score matched the TUG score's ability to discriminate between older adults with and without a history of falls.[120] More recently, a cross-sectional study of community-dwelling older adults (n= 377) determined that mean TUG-DT discriminated between men with and without a history of falls, whereas mean TUG score alone could not discriminate for either sex, but that both tests had limited diagnostic accuracy across sexes [TUG-DT: Female area under the curve (AUC)= 0.57, Male AUC= 0.68; TUG: non-significant results].[131]

Simple tests of standing balance such as the SLS test have also been suggested for fall risk screening by the CDC's falls screening and prevention algorithm for older adults.[106] Along with the TUG, the SLS is one of the most commonly used balance tests in geriatric and general rehabilitation settings.[132] To perform the SLS, individuals are instructed to place their hands on their hips, lift one foot off of the floor and hold this timed position for as long as possible. It takes approximately three minutes to administer[107,113] and longer times are indicative of better balance. For measurement properties, the SLS score has demonstrated excellent inter-rater (ICC= 0.93 to 0.99)[117] as well as good to excellent intra-rater reliability (ICC= 0.69 to 0.99)[113,117] in community-dwelling older adults. In terms of known-groups validity, the SLS score has distinguished between community-dwelling older adults with and without a history of falls[113,123] and gait aid users and non-users.[117] The SLS has also distinguished between individuals classified as low risk and high risk for falls using the Elderly Falls Screening Test[133] and can predict injurious falls in older adult women.[134,135]

A more recently developed balance test, the Brief BESTest, may also be an appropriate fall risk screening measure in older adults.[107] The BESTest[136] and its shortened versions (Brief BESTest and Mini BESTest) have been designed to provide a more comprehensive assessment of balance and its sub-systems, with the Brief BESTest version being the shortest and easiest to administer.[111] A distinguishing quality of these tests is the inclusion of change-in-support reactions to manual perturbations as part of the assessment. The Brief BESTest has six items (condensed from the 36-item full BESTest), with each task covering one of six systems of balance control evaluated in the full version. It takes less than 10 minutes to administer[114-116] and a lower score (percentage out of 100 or raw score out of 24) is indicative of worse balance/mobility. In regard to psychometric properties, the Brief BESTest score has demonstrated convergent validity (r= 0.60 to 0.77)[133,137] with other tests of balance, balance and mobility and balance confidence, as well as excellent inter-rater (ICC= 0.93 to 0.99) and intra-rater (ICC= 0.82 to 0.94) reliability in community-dwelling older adults,[137] older adults in the nursing home[115] and persons with neurological diagnoses.[111] The Brief BESTest score can discriminate between community-dwelling and institutionalized older adults and with and without a history of falls as well as identify fall status with good accuracy in both populations (AUC= 0.76 for community-dwelling; AUC= 0.75 for institutionalized).[115,137] The Brief BESTest score has also shown good predictive validity for falls in people with Parkinson's disease (AUC= 0.76).[116]

Other balance measures that have been suggested for fall risk screening in older adults include the five-repetition chair stand test[106,107] and the Berg Balance Scale (BBS) for a more detailed falls risk assessment.[107,132]

1.2.3 Balance and Falls in Older Adults with COPD

1.2.3.1 COPD: What Does Balance Look Like?

There have been many studies investigating balance control in COPD. Balance deficits in COPD have remained significant and persistent across a variety of balance tests and disease severities when compared to healthy older adults of a similar age.[16-27] The first investigation identified impairments in strength, coordination, motor speed and higher cognitive functions among nearly half of 203 older adults with advanced COPD compared to age- and sex-matched controls.[138] In line with these findings, a subsequent study demonstrated that 30 people with COPD (FEV_1 28% predicted) on supplemental oxygen had worse performance in functional balance (Community Balance and Mobility Scale and TUG) and greater postural sway than healthy controls.[11] In a large cross-sectional analysis of a prospective cohort study on the systemic effects of COPD, 1202 COPD patients (FEV_1 62% predicted) showed deficits in balance compared to matched controls for sex, age and race (n= 302).[6], as measured by the tandem stance task and Functional Reach Test.[6] Following this, results from the two-year prospective study determined that these impairments in balance increased the risk of disability in COPD (FEV_1 77% predicted; n= 1051), highlighting the importance of secondary effects of the disease.[7]

A recent cross-sectional study on balance measured using the TUG in older adults with COPD (FEV_1 63.8% predicted; n= 160) compared balance across all grades of the disease.[21] It was found that balance was impaired compared to normative values for healthy older adults in just under half of the total COPD participants. Although demonstrated in mild COPD, balance impairments were more pronounced in the severe to very severe COPD group.[21] Contrary to these results, another study concluded that disease severity in COPD (FEV_1 45% predicted; n= 47) had no effect on balance performance, as all disease grades demonstrated similar impairments in static and dynamic balance as measured by the SLS (on a force platform) and TUG.[23] However, the authors explain this may be a result of their particularly high-functioning sample as demonstrated by TUG scores.[23]

Balance has also been studied in relation to acute exacerbations. In one small study significant balance impairments in both stable patients with moderate to severe COPD (FEV_1 29% predicted; n= 29) and patients with acute exacerbations of COPD (FEV_1 28% predicted; n= 17) were demonstrated on the TUG, SLS and ABC scale.[25] Significant balance deficits were also shown on the BBS in the acute exacerbation COPD group.[25] Overall, those with acute exacerbation COPD demonstrated worse balance impairments than stable COPD patients, emphasizing particularly impaired balance control during acute phases of the disease.[25]

Centre of pressure parameters have also been used to identify balance deficits in COPD. In a small study (FEV_1 33.1 % predicted; n= 12) participants with COPD demonstrated greater mediolateral centre of pressure displacement and greater angular hip motion compared to controls than healthy controls.[17] This mediolateral displacement increased even more after exercise.[17] Greater mediolateral displacement has been linked to a higher risk of falls[104] and the additional displacement post-exercise may implicate the role of trunk muscle strength in balance control in COPD.[17,139,140] In relation to this, using a cross-sectional design, the relationship between balance control, proprioception and inspiratory muscle strength in patients with COPD in a laboratory setting was examined.[26] Compared to matched controls, participants with moderate COPD (FEV_1 110% predicted; n= 18) demonstrated postural instability as measured by greater anterior-posterior sway. Increased reliance on ankle muscle proprioceptive signals and reduced reliance on back muscle proprioceptive signals were also observed, with the greatest reliance demonstrated by those with inspiratory muscle weakness. These findings suggest that the observed proprioceptive changes and postural instability in COPD may be explained by a lack of contribution of inspiratory muscles to trunk stability.[26]

Very few studies have comprehensively evaluated the underlying contributions to balance deficits in COPD. One study comprehensively evaluated the underlying systems of balance deficits in 37 participants with COPD (FEV_1 39% predicted) using the six subsystems of balance in the BESTest.[19] Compared to controls, participants with COPD demonstrated a unique profile of balance impairment with deficits in all six balance subcomponents, but with more pronounced deficits in the areas of biomechanics, transitions and gait.[19] In addition to this, people with COPD exhibited a delayed reaction time to perturbations compared to controls.[19]

1.2.3.2 COPD: Fall Risk, Prevalence and Injury

Falls constitute a serious problem for people with COPD. The self-reported prevalence of falls in studies of people with COPD (44 to 51%[16,20,24,25,30,33]) has been consistently higher than that reported by the general older population (29 to 33%[39-41,81]). Recently, findings from a large matched cohort study examining the incidence of falls in 44,400 COPD patients from the UK showed that persons with COPD were 55% more likely than the matched control group (n= 175,545) to have an incident record of a fall even after adjusting for other fall risk factors.[31] Moreover, in a cross-sectional study of 4,000 older adult women, COPD was second to osteoarthritis in its association with a higher odds of falling (adjusted OR= 1.48, 95% CI 1.19 to 1.84) [28] and in a further study, was reported to be the only chronic condition to predict falls in an analysis of data from over 16,000 Canadians > 65 years.[29] A previous prospective cohort study (n= 101) in individuals with moderate to severe COPD (FEV_1 46.4% predicted) determined that 31.7% of patients reported at least one fall during a six-month period and that the projected annual rate of falls was 1.2 falls per person.[33] In line with this finding, another small prospective cohort study (n= 41) identified an incident rate of 1.17 falls per person per year in those with COPD (FEV_1 45.1% predicted).[30] A prospective study comparing falls in elderly outpatients with a diagnosis of COPD (FEV_1 51.2% predicted; n= 747) versus asthma (FEV_1 64.1% predicted; n= 829) identified the fall incidence rate (fall per person per year) to be 1.49 in the COPD group, which was higher than the asthma group[34] and six times more than reported for older adults.[81] In terms of the consequences of falls, fall-related injuries are frequent in COPD[141,142] and a falls history in severe COPD is considered a strong predictor of all-cause mortality.[143]

Balance impairments in people with COPD have been linked to an increased risk of falls in this population.[16,19,20,24,25,30] A cross-sectional study was used to examine the relationship between balance and falls history in older adults with COPD (FEV_1 42% predicted; n= 39).[16] Results showed that performance on the TUG, BBS and self-reported balance confidence discriminated between self-reported fallers and non-fallers with COPD.[16] In addition to this, another study investigated postural control using the Sensory Organization Test and fall risk in 20 people with moderate to severe COPD (FEV_1 46.7% predicted) and found that the COPD group exhibited marked balance deficits and fell more frequently compared to matched controls.[20] These results are in line with a subsequent study where patients with COPD (FEV_1 39.4% predicted; n= 37) showed slower and less successful balance recovery reactions in response to unexpected simulated forward falls compared to age-matched controls.[19] In 2015, 41 older adults with COPD (FEV_1 45.1% predicted) were followed in a 12-month prospective study and it was reported that older adults experiencing falls were mainly self-reporting loss of balance as the cause of their fall.[30] Furthermore, an investigation of balance test scores (BBS, SLS, TUG, ABC scale) in older adults with stable and acute exacerbations COPD (FEV_1 29% predicted for stable COPD; FEV_1 28% predicted for acute exacerbation COPD; n= 46) found that balance scores were significantly lower in individuals with a falls history.[25] More recently, another study also found that participants with COPD (FEV_1 50%

predicted; n=93) with a history of falls demonstrated significantly worse balance scores compared to persons without a falls history using the BBS and Tinetti Balance Scale.[24]

Identifying risk factors for falls in COPD is a growing area of research. A narrative review was the first to provide an overview of hypothetical risk factors in COPD and suggested lower limb muscle weakness and impaired activities of daily living (e.g. lower physical activity level or sedentary time) as important factors likely associated with an increased fall risk in this population.[10] To date, only a few studies have prospectively evaluated fall risk factors in COPD. A recently conducted prospective cohort study conducted followed 829 elderly outpatients with asthma (FEV_1 64.1% predicted) and 747 elderly outpatients with COPD (FEV_1 51.2% predicted) for 12 months and found that there was a significantly increased fall incidence rate ratio for both asthma and COPD subjects using multiple medications, experiencing depression and of advanced age (80 to 90 years old).[34] An additional 12-month prospective study following 41 subjects with COPD (FEV_1 45.1% predicted) found that a having a history of falls in the previous year, a greater number of comorbidities, pack-years, medications and risk factors, as well as increased fear of falling and poor balance were independently associated with a higher fall incidence.[30] However, after adjusting for age, only having a history of falls in the previous year, a greater number of comorbidities and a greater number of pack-years were associated with an increased fall incidence rate ratio.[30] A six-month prospective cohort study of 101 people with COPD (FEV_1 46.4% predicted) identified that female sex, older age, fall history and coronary heart disease were all risk factors for falls, with fall history

(OR= 7.36, 95% CI 2.39 to 22.69) and coronary heart disease (OR= 7.07, 95% CI 2.14 to 23.36) as the greatest predictors of falls in COPD.[33] Other emerging risk factors for falls in COPD that warrant further investigation with large prospective study designs include disease severity,[11,12,144] gait instability,[10,19,63] cognitive impairments,[10,90,145,146] skeletal muscle dysfunction,[8,10,19,24,89,147] trunk muscle weakness,[17,26,140] malnutrition,[10] altered proprioception,[26] dyspnea,[10,16,33] visual deficits,[10] assistive device use,[10] supplemental oxygen use,[16,33] exacerbations[10,25,32] and poor balance confidence.[16,25]

1.2.3.3 Fall Prevention in COPD

Despite the accumulating evidence on risk factors for falls and the high prevalence of falls in people with COPD, there are currently no established fall prevention programs specific to this population. Fortunately, the ATS/ERS have updated international guidelines for pulmonary rehabilitation to recommend a balance test as part of an outcomes assessment for people with COPD,[47] but there is still a need to consider balance training and fall prevention strategies as part of the management of COPD. In previous work, balance training has been shown to be effective for improving balance performance in people with COPD[148-151] and feasible for implementation into pulmonary rehabilitation.[152] However, there remains a need to effectively identify those at risk for falls so that implementation of prevention and risk reduction efforts can be targeted to individuals at the highest risk.

1.2.2.4 Balance Screening Tests for Fall Risk Assessment in COPD

Based on international best practice guidelines for fall prevention in older adults and specific clinical populations,[43,46,106] an integral step in the development and implementation of successful fall prevention includes balance screening for fall risk assessment.[107] This occurs at the early stages of fall prevention, where patients who report a history of falls or concerns about balance receive a short balance test to screen for balance impairments. This is a pivotal component as the score on the balance screening tests determines whether the patient is at high or low risk for falls, and ultimately the need for more comprehensive balance assessment and training, as well as multifactorial risk factor reduction.[107]

There is no gold standard fall risk screening test in COPD and limited research on psychometric properties of balance screening tests for fall risk assessment in this population. Although the ATS/ERS now suggests a balance assessment as part of pulmonary rehabilitation outcomes, there was no balance test specified as part of their recommendation. There is a need to address this gap in order to inform clinical practice and to identify persons who would benefit from a fall prevention intervention. Although there have been many tests used to assess balance in people with COPD,[76] only a few are considered appropriate for fall risk screening based on their short length to administer, acceptability to clinicians, and strength of psychometric properties demonstrated in COPD or similar populations (older adults). Based on the currently available literature[16,25,76,114,145,146,152-157] (please refer to Appendix B) and our consultations with clinicians in respiratory medicine, the leading balance screening tests for consideration in COPD are the Brief BESTest, SLS, TUG and TUG-DT.

In terms of the COPD population, the Brief BESTest has demonstrated high acceptability to clinicians in pulmonary rehabilitation with strong content validity,[152] as well as excellent inter- (ICC= 0.86 to 0.97) and intra-rater (ICC= 0.82 to 0.93) reliability in patients with mild/moderate/severe COPD.[114,153] The Brief BESTest has also shown convergent validity with more extensive measures of balance (r= 0.53 to 0.90) and an ability to differentiate between patients with and without a history of falls in COPD, as well as an ability to identify fall status with acceptable accuracy in patients with moderate to severe COPD (AUC= 0.78).[153]

The SLS is commonly used in the COPD population to assess postural control[76] and has demonstrated excellent intra-rater (ICC= 0.91) reliability in elderly males with mild to severe COPD.[154] The SLS has also been shown to discriminate between those with an acute exacerbation of COPD, stable COPD and age-matched controls, as well as individuals without a history of falls, individuals with a history of one fall and individuals with a history of two or more falls in acute exacerbation COPD and stable COPD.[25]

Similar to the SLS, scores on the widely used TUG test have also been shown to discriminate between acute exacerbation COPD, stable COPD, age-matched controls[25] and between persons without a history of falls, persons with a history of one fall and persons with a history of two or more falls in COPD[16,25] and acute exacerbation COPD.[25] Furthermore, performance on the TUG has been shown to identify fall status in patients with mild to severe COPD with acceptable accuracy (AUC= 0.77).[155] In addition, the TUG has shown excellent inter-rater (ICC= 0.99 to 0.997) and intra-rater (ICC= 0.85 to 0.96) reliability in both advanced and less advanced stages of the disease.[154-157] The TUG has also demonstrated an ability to detect functional disabilities as well as a longitudinal association with deterioration in disease-related health status among patients with advanced COPD.[158]

Lastly, the TUG-DT is not currently a commonly used balance test in COPD, however it may be a relevant fall risk screening test for this population given the demonstrated impairments in dual-task performance in COPD that may be attributable to cognitive and/or balance deficits.[145,146] To our knowledge, there are no studies that have explored the measurement properties of TUG-DT in COPD.

Taken together, this literature supports the need to further examine the measurement properties of short balance screening tests for fall risk assessment in COPD within a single study to enable meaningful comparison among them. In order to develop effective fall prevention and risk reduction strategies, we need to identify the optimal balance screening test with strong psychometric properties and clinical feasibility for fall risk assessment in the COPD population.

1.3 Summary of Research Objectives

Based on extensive literature showing frequent problems with balance and an increased risk of falls in people with COPD, there is a pressing need to evaluate strategies for fall risk assessment and prevention in this patient population. Before fall prevention strategies can be implemented in primary care and rehabilitation settings, the optimal screening test for fall risk assessment in COPD needs to be identified. Therefore, the specific aims of my thesis are:

1. To determine the construct validity (convergent and known-groups) of four short balance screening measures (Brief BESTest, SLS, TUG and TUG-DT) for fall risk assessment in people with COPD (≥ 60 years). We hypothesized that the balance screening tests would demonstrate moderate to strong correlations with a comprehensive measure of balance, a measure of balance confidence and a measure of muscle strength, and moderate correlations with measures of exercise tolerance, functional limitation, disability and prognosis. We also expected that lower balance scores would categorize individuals with a falls history, individuals with high fall risk status, gait aid users, individuals who worry about falls, supplemental oxygen users and individuals with a worse prognosis.
2. To determine the criterion (concurrent) validity of four short balance screening measures (Brief BESTest, SLS, TUG and TUG-DT) for identifying individuals with a falls history in COPD (≥ 60 years). We hypothesized that all balance

screening measures would demonstrate an acceptable accuracy for identifying individuals with previous falls (AUC=0.7).

These aims will be achieved using a cross-sectional analysis of an ongoing prospective cohort study in older adults with COPD. (Chapter 2) It is hoped that this thesis work will help to inform effective implementation of fall risk screening in patients with COPD in order to identify persons at high risk of falling and in need of a fall prevention intervention.

Chapter 2

Fall Risk Assessment in People with Chronic Obstructive Pulmonary Disease (COPD): A Comparison of Four Short Balance Screening Tests

Authors:

Rachel McLay[1]

Marla Beauchamp[1-3]

Ayse Kuspinar[1]

Julie Richardson[1]

[1]School of Rehabilitation Sciences, McMaster University, Hamilton, Ontario, Canada

[2]St. Joseph's Healthcare Hamilton, Ontario, Canada

[3]West Park Healthcare Centre, Toronto, Ontario, Canada

2.1 Abstract

Background: People with COPD have significant balance impairments and an increased risk of falls. The psychometric properties of short balance screening tests to inform fall risk assessment in COPD have not been studied. The objective of this study was to compare the validity of four short balance tests suitable for fall risk screening to identify the most optimal screening tool(s).

Methods: Participants ≥ 60 years with COPD attended a single physical assessment with completion of questionnaires. Correlation coefficients were used to describe relationships between the Brief Balance Evaluation Systems Test (Brief BESTest), Single-Leg Stance (SLS), Timed Up and Go (TUG) and Timed Up and Go Dual-Task (TUG-DT) tests, and other measures of balance, measures of muscle strength, exercise tolerance, functional limitation, disability and prognosis. Independent *t*-tests or Mann-Whitney *U* tests were used to examine differences between groups with respect to fall risk. Receiver operating characteristic curves were plotted to examine the ability to of the screening tests to identify individuals with previous falls.

Results: Seventy-three participants with COPD completed the study (age 73.0 ± 6.9 years; FEV_1 47.0 ± 19.8% predicted). All balance screening tests demonstrated moderate to strong correlations with the Berg Balance Scale (r= 0.47 to 0.80, p<0.05) and Activities-specific Balance Confidence scale (r= 0.44 to 0.61, p<0.05). The Brief BESTest and SLS showed the strongest correlations with other balance measures and demonstrated the most consistent ability to discriminate between fall risk groups. The

Brief BESTest was the only screening test that identified individuals who reported a previous fall with acceptable accuracy (AUC= 0.7).

Conclusions: The Brief BESTest and SLS show the most promise as balance screening tools for fall risk assessment in older adults with COPD. These results will need to be prospectively confirmed with a larger sample size. **Keywords:** Balance, Falls, COPD

2.2 Introduction

Chronic obstructive pulmonary disease (COPD) is a complex, multisystem disease with important secondary characteristics beyond the progressive deterioration in lung function.[6-10,12,13,15,48] Emerging research over the past 10 years has shown that older adults with COPD experience considerable balance impairments[6,11,17,19,20,23,25] and a high number of falls.[16,19,20,30,31,33,34] Although declines in balance are typical with advanced age,[85,87] balance deficits in older adults with COPD remain pronounced compared to age-matched healthy older adults using both clinical balance tests and posturography, suggesting a link between the disease and balance impairments. These observed balance deficits may explain the increase in fall risk (fall incidence reported to be 1.17 falls per person per year) among persons with COPD.[16,19,20,24,25] Older adults diagnosed with COPD fall at a greater rate than persons of the same age without COPD[16,30,33,39-41,81] and COPD itself has been identified as the single-most predictive chronic condition of falls in older adult Canadians.[29]

Unintentional falls are the leading reason for injury-related hospitalizations among older Canadians[71] and pose a tremendous and costly health concern for older adults worldwide.[72] Although fall risk reduction and prevention guidelines have been developed by international organizations to address falls among older adults,[43,46,106] there have yet to be any recommendations specifically for older adults with COPD. Since older adults with COPD experience the cumulative effects of aging and disease on fall risk, there is a need to develop population-specific fall risk assessment strategies to identify persons at highest risk of falling and most likely to benefit from intervention.

Balance screening is a fundamental part of all evidence-based clinical practice guidelines for fall prevention in community-dwelling older adults.[43,46,106,107] It is recommended that older patients who may be at increased risk of falls receive a brief balance test to determine their level of fall risk and in turn, whether or not they require further intervention.[43,46,106,107] A key consideration in of this assessment is ensuring the balance screening tools have established psychometric properties in the relevant population. To date, there is no gold standard balance screening test for fall risk assessment in older adults, or in people with COPD. Current guidelines for pulmonary rehabilitation by the American Thoracic Society/European Respiratory Society recommend balance testing as part of the an outcomes assessment for this population, however no recommendations are provided for specific tests.[47]

The overall objective of this study was to identify the optimal balance screening tool(s) for fall risk assessment in older adults with COPD by comparing the validity of four carefully selected short balance tests: the Brief Evaluation Sysetms Test (Brief BESTest), Single-Leg Stance (SLS), Timed Up and Go (TUG) and Timed Up and Go Dual-Task (TUG-DT). The specific aims of this study are:

1) To determine the construct validity (convergent and known-groups) of the Brief BESTest, SLS, TUG and TUG-DT for fall risk assessment in people with COPD (≥ 60 years). We hypothesized that the balance screening measures would demonstrate moderate to strong correlations with a measure of comprehensive balance, a measure of balance confidence and a measure of muscle strength, and moderate correlations with

measures of exercise tolerance, functional limitation, disability and prognosis. We also expected that lower balance scores would categorize individuals with a falls history, high fall risk status, gait aid users, individuals worried about falling, supplemental oxygen users and individuals with a worse prognosis.

2) To determine the criterion (concurrent) validity of the Brief BESTest, SLS, TUG and TUG-DT for identifying individuals with a falls history in COPD (≥ 60 years). We hypothesized that all balance screening measures would demonstrate an acceptable accuracy for identifying individuals with previous falls [Area Under the Curve (AUC)=0.7].

2.3 Materials and Methods

2.3.1 Study Design

This was a cross-sectional analysis of an ongoing prospective cohort study. Approval of the study protocol was obtained from the Hamilton Integrated Research Ethics Board (HiREB #3331 and #4335) and the Joint West Park Healthcare Centre-Toronto Grace Health Centre Research Ethics Board (JREB #17-018-WP).

2.3.2 Participants

Participants with COPD were recruited from respirology clinics at the Firestone Institute for Respiratory Health in Hamilton and at West Park Healthcare centre in Toronto, as well as from a local community health centre in Hamilton, through referrals from respirologists, posted advertisements and research presentations. Individuals were recruited between January 2018 and July 2019.

Persons who met the following inclusion criteria were considered eligible to participate: 1) aged ≥ 60 years; 2) physician-diagnosis of COPD, emphysema or chronic bronchitis (based on Global initiative for chronic Obstructive Lung Disease guidelines or a traditional FEV_1/FVC ratio of less than 0.70[48]); and 3) an ability to provide written informed consent. Persons were excluded if they were unable to communicate due language impairments (e.g. aphasia) or use of a non-English language, if they experienced other health conditions that significantly limited their mobility (e.g. recent stroke, Parkinson's Disease) or if they were unable to follow instructions due to dementia/severe cognitive impairment.

A sample size of 74 was targeted to achieve 80% power in detecting at least a moderate correlation (r= 0.3) between measures with an alpha of 0.05 for convergent validity. For known-groups validity, a minimum sample size of 22 per group was considered adequate for detecting a mean difference of 3.1 seconds on the TUG between persons with and without a history of falls in COPD[16] (α= 0.05, power 80%).

2.3.3 Data Collection

People with COPD interested in participating in the study were screened by telephone for eligibility. Persons who met eligibility criteria were invited to attend a single two-hour assessment session at a quiet university lab or hospital space. Demographic and medical information were retrieved from the patient's medical record. A trained physiotherapist with a minimum of five years of work experience administered first the physical tests, followed by the questionnaires, and consistently completed in this order for all subjects. The order of the primary balance tests under investigation was randomized and administered first (Brief BESTest, SLS, TUG and TUG-DT), followed by secondary measures of balance, measures of lower body strength and exercise tolerance, and lastly questionnaires on balance confidence, disability, functional limitations and prognosis. Subjects were instructed to wear comfortable clothing for the assessment and rest as needed during the session.

2.3.4 Primary Measures

Four balance measures potentially suitable for fall risk screening were selected based on the following criteria: 1) administration time < 10 minutes; and 2) commonly used by clinicians in respiratory rehabilitation or preliminary evidence for their psychometric properties in older adults.

1) The Brief BESTest[111] is the most condensed version of the 36-item BESTest,[136] containing six tasks for each of the six sub-systems of balance control included in the parent test and evaluates both static and dynamic balance. The test takes less than 10 minutes to administer[114-116] and is scored out of 24 points, or 100%. A lower score/percentage represents more impaired balance. The Brief BESTest score has demonstrated excellent inter- (ICC= 0.86 to 0.97) and intra-rater (ICC= 0.82 to 0.93) reliability across all severities of COPD,[114,153] as well as excellent inter- (ICC= 0.93) and intra-rater (ICC= 0.82) reliability in community-dwelling older adults,[137] and is considered a highly acceptable measure by clinicians working in pulmonary rehabilitation.[152] There is some available evidence to support the convergent validity

of the Brief BESTest with more extensive measures of balance (r= 0.53 to 0.90) and also to identify individuals with a falls history COPD.[153]

2) The SLS is a simple test where the participant is asked to stand on one leg for as long as possible (limit of 60 seconds) with hands on their hips. It takes approximately three minutes to administer[107,113] and has been identified in a recent systematic review as one of the top four most commonly used tests to assess balance in COPD.[76] It is also frequently used in geriatric rehabilitation[132] and has been recommended for fall risk screening among older adults.[106] The longer a participant is able to hold SLS, the more advanced their balance skills are. In previous work, the SLS score has shown excellent intra-rater reliability in COPD,[154] as well as excellent inter-rater (ICC= 0.93 to 0.99)[117] and intra-rater (ICC= 0.69 to 0.99) reliability[113,117] in community-dwelling older adults. The SLS has also been able to cross-sectionally differentiate between persons with no history of falls, persons with a history of one fall and persons with a history of two falls in both acute exacerbation and stable COPD groups[25] as well as adults ≥ 50 years classified as high and low risk for falls (based on the Elderly Falls Screening Test).[133]

3) The TUG[110] is a widely used measure of balance and mobility in both healthy older adult and COPD populations. The participant is seated in a chair and the timed task involves the participant getting up from the chair, walking three metres and then turning around to walk back and return to a seated position at their usual walking speed. The individual is permitted to use their gait aid if preferred and a greater time taken to complete the TUG indicates worse balance/mobility. The TUG takes five

minutes to administer[107,112,113] and has been suggested as a potential screening tool by two major clinical practice guidelines for fall prevention in older adults.[43,106] Scores on the TUG have demonstrated excellent inter-rater (ICC= 0.99 to 0.997) and intra-rater (ICC= 0.85 to 0.96) reliability across varying COPD severities.[154-157] The TUG has evidence for convergent validity with other tests of balance (r= 0.66) in older adults[110,112,118,119] and there is preliminary evidence to show it is able to identify individuals with and without a falls history in COPD.[16,155]

4) The TUG-DT involves the same tasks and administration time as the usual TUG,[107,112,113] but the participant is asked to count backwards by threes while they complete the test. Again, individuals are permitted to use their gait aid if needed. The TUG-DT is used in older adult populations to examine the relationship between balance/mobility and dual-task performance or cognitive impairment which has shown to be important for fall risk.[91,102] Among older adults, the TUG-DT has demonstrated convergent validity with more extensive tests of balance (r= 0.66) and excellent intra-rater (ICC= 0.94 to 0.98) and inter-rater (ICC= 0.99) reliability,[119,129] as well as a comparable ability to the TUG alone in discriminating between older adults with and without a history of falls.[120,131]

2.3.5 Secondary Measures

Comprehensive measures of balance included the Berg Balance Scale (BBS) and the Activities-specific Balance Confidence scale (ABC scale). The BBS[159] is a 14-item balance test recognized as a psychometrically robust gold standard tool for comprehensively assessing balance (higher scores indicate better balance).[128,160] The ABC scale is a measure of balance confidence and asks participants to rate their confidence in performing 16 different progressively difficult activities without losing their balance on a scale from 0 to 100%, where 100% is completely confident.[161] The score has been shown to predict falls in community-dwelling older adults.[128,162]

Functional lower body strength was measured with the 30-second repeated Chair Stand test (Chair Stands) which involves counting the number of sit-to-stands the participant can complete in 30 seconds. A higher number of chair stands indicates greater lower body strength. This test score has been validated as a surrogate measure of strength in older adults with COPD.[163]

Exercise tolerance was measured using the six-minute walk test (6MWT). This test measures the distance a participant can walk in six consecutive minutes, where a further distance walked indicates better exercise capacity.[164] The score has well-established psychometric properties in COPD.[165,166]

Functional limitation in terms of perceived limitations in physical functioning was assessed using the physical-function scale (PF-10), which is a sub-score of the 36-Item Short-Form Health Survey (SF-36).[167,168] Functional limitation or disability attributable to dyspnea was measured using the widely used Medical Research Council dyspnea scale (MRC dyspnea scale),[169] where the participant is asked to rate their breathlessness on a scale from one to four (a higher number indicates greater disability).[170]

Prognosis or disease severity was measured using the validated Body mass index (BMI), airflow Obstruction, Dyspnea and Exercise capacity (BODE) index,[171] where a total score out of 10 points is assigned based on spirometry, dyspnea, 6MWT distance and BMI. A greater amount of points indicates more severe disease or a worse prognosis.

Falls were ascertained by asking if the participant had experienced a fall in the past year upon providing the definition: "A fall would be when you find yourself suddenly on the ground, without intending to get there, after you were either in a lying, sitting or standing position."[172] The Elderly Falls Screening Test (EFST) was used to assess fall risk and takes into consideration falls history, injurious falls and gait speed. A score of < 2 classifies the participant as "low-risk" for falls and a score of ≥ 2 classifies the participant as "high-risk." The EFST score has predictive validity for falls in community-dwelling older adults.[172]

2.3.6 Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Statistical Package for Social Sciences) version 25.0.[173] Descriptive statistics were computed (mean, SD, total numbers) for collected demographic measures. In order to determine the convergent validity of the four balance screening tests, Pearson (normal distribution, continuous data) or Spearman (non-normal distribution, ordinal data) correlation coefficients were used to describe the relationships between the balance screening tests and the BBS, ABC scale, Chair Stands, 6MWT, MRC, BODE and PF-10. Cohen's interpretation was used to categorize correlations as weak (0.1), moderate (0.3) or strong (0.5).[174] In order to determine the known-groups validity of the four balance screening tests, differences were examined between groups with respect to falls, fall risk, gait aid use, worry about falling, supplemental oxygen use and prognosis using Independent *t*-tests (normally distributed data) or Mann-Whitney *U* tests (non-normally distributed or ordinal data). Lastly, in order to determine the criterion (concurrent) validity of the four balance screening tests, Receiver Operating Characteristic (ROC) curves were plotted for each of the tests to examine their ability to identify individuals with a falls history, using the AUC as a measure of the test's accuracy. By convention, AUC of 0.7 or greater was considered acceptable accuracy for screening.[175] For tests with acceptable accuracy, the optimal cut-off value was determined using the point closest to the upper left-hand corner of the ROC curve (point that optimizes sensitivity and specificity). Normality was determined using both graphical methods and the Shapiro-Wilk test.

Before running analyses, the data were examined for outliers using a graphical method and only extreme outliers were removed and considered missing data. For bivariate correlations, missing values were excluded pairwise, meaning that for a given correlation between two variables, missing values were excluded from the analysis but all cases with non-missing values were still used; for Independent *t*-tests or Mann-Whitney *U* tests, missing values were excluded analysis by analysis, meaning missing values were excluded from the analyses but each analysis used all cases that had non-missing values for the given variable; and for ROC curves, system-missing values (any values that were completely missing or blank in the dataset) were excluded from the analysis. Ceiling and floor effects were also examined for the balance screening tests by calculating the percent of participants at the upper- and lower-limits of the test score. A ceiling or floor effect $\geq$ 15% was considered significant.[176] Where ceiling and floor effects could not be calculated due to the type of test, refusal rates were examined. Significance level was set at 0.05 (one-tailed).

2.4 Results

2.4.1 Participants

A total of 73 people with COPD (age 73.0 ± 6.9 years; FEV_1 47.0 ± 19.8% predicted) completed the study. Participant characteristics are presented in Table 1. The study sample included an even number of male and female participants. On average, participants had a smoking history of 45.9 ± 27.3 pack years and 4.6 ± 2.3 chronic conditions. Thirty participants (41.1%) reported having at least one fall in the previous year, with 45 (61.6%) having self-reported balance problems and 36 (49.3%) reporting they were worried about falling. Twenty participants (27.4%) were on supplemental oxygen and 36 (49.3%) used a gait aid. In terms of floor and ceiling effects of the balance screening tests, the Brief BESTest and SLS had negligible floor effects (1.4% and 4.3%, respectively) and no ceiling effects. No subjects refused or were unable to complete the TUG and 5.5% of subjects refused or were unable to complete TUG-DT.

Table 1. Participant Characteristics (n= 73)

Variable	Result
Male/Female [n (%)]	37 (50.7)/ 36 (49.3)
Age (years)	73.0 ± 6.9
Body Mass Index (kg/m^2)	28.2 ± 7.1
Smoking History (pack-years)	45.9 ± 27.3
Supplemental Oxygen (n, %)	20, 27.4
Gait Aid (n, %)	36, 49.3
Fall in Previous Year (n, %)	30, 41.1
One Fall in Previous Year (n, %)	18, 24.7
Two or More Falls in Previous Year (n, %)	12, 16.5
Self-Reported Balance Problems (n, %)	45, 61.6
Worried about Falling (n, %)	36, 49.3
Number of Chronic Conditions (including COPD)	4.6 ± 2.3
FEV_1 (L)	1.2 ± 0.6
FEV_1 (% predicted)	47.0 ± 19.8
FVC (L)	2.5 ± 1.0
FVC (% predicted)	71.4 ± 18.2
FEV_1/FVC	0.48 ± 0.1

Note. All values are mean ± Standard Deviation except when indicated; FEV_1: Forced Expiratory Volume in 1 second; FVC: Forced Vital Capacity

2.4.2 Convergent Validity

All balance screening tests were moderately to strongly correlated with the BBS (r= 0.47 to 0.80), with the strongest correlations demonstrated by the Brief BESTest (r= 0.80) and SLS (r= 0.71) (Table 2). All screening tests were moderately to strongly correlated with the ABC scale (r= 0.44 to 0.61) and 6MWT (r= 0.39 to 0.69). All screening tests except for the SLS showed moderate to strong correlations with Chair Stands (r= 0.51 to 0.75), moderate to strong correlations with BODE (r= 0.31 to 0.50) and moderate correlations with the PF-10 (r= 0.30 to 0.41). The Brief BESTest and TUG were the only two tests to moderately correlate with the MRC dyspnea scale (r= 0.33 and 0.30, respectively).

Table 2. Convergent Validity of Balance Screening Tests (n= 73)

Test	*BBS*	*ABC scale*	*Chair Stands*	*6MWT*	*PF-10*	*BODE index*	*MRC dyspnea scale*
Brief BESTest	0.80*	0.61*	0.51*	0.62*	0.30*	-0.31*	-0.33*
SLS	0.71*	0.52*	0.27*	0.39*	0.19	-0.08	-0.17
TUG	-0.62*	-0.46*	-0.75*	-0.69*	-0.39*	0.50*	0.30*
TUG-DT	-0.47*	-0.44*	-0.70*	-0.65*	-0.41*	0.50*	0.27*

Note. Brief BESTest: Brief Balance Evaluation Systems Test; SLS: Single-Leg Stance; TUG: Timed Up and Go; TUG-DT: Timed Up and Go Dual-Task; BBS: Berg Balance Scale; ABC scale: Activities-Specific Balance Confidence Scale; Chair Stands: 30-second repeated Chair Stands; 6MWT: Six-Minute Walk Test; PF-10: Physical-Functioning scale; BODE index: Body mass index, airflow Obstruction, Dyspnea and Exercise capacity index; and MRC dyspnea scale: Medical Research Council dyspnea scale
* = significant at the 0.05 level (one-tailed)

2.4.3 Known-Groups Validity

All balance screening test scores were able to discriminate between individuals classified as high risk and low risk for falls by the EFST as well as between gait aid users and non-users (Table 3). The Brief BESTest and SLS were the only two tests to distinguish between individuals with a history of falls and without a history of falls, as well as individuals worried about falling and not worried about falling.

Differences in balance scores were demonstrated between supplemental oxygen users and non-users only for the TUG and TUG-DT (Table 4). All balance screening test scores except for the SLS score discriminated between individuals with worse prognosis and better prognosis based on the BODE index score.

2.4.4 Concurrent Validity

The AUCs for identifying individuals with a history of falls ranged from 0.58 to 0.70 for the different balance screening tests (Table 5). The Brief BESTest was the only screening test to demonstrate acceptable accuracy for identifying individuals with previous falls (AUC= 0.70, 95% CI 0.58 to 0.83, p= 0.003). The SLS showed borderline acceptable accuracy in identifying individuals with a falls history (AUC= 0.69, 95% CI 0.56 to 0.82, p= 0.007).

The cut-off value for identifying individuals with a fall history for the Brief BESTest was 64.6 percent (80.0% sensitivity and 55.8% specificity) (Figure 1). The cut-off value for SLS was 7.0 seconds (78.6% sensitivity and 53.7% specificity).

Table 3. Known-Groups Validity of Balance Screening Tests

Test	*Falls History (n= 30) x No Falls History* (n= 43)	*High Risk (n= 25) x Low Risk* (n= 48)	*Gait Aid (n= 36) x No Gait Aid* (n= 37)	*Worried (n= 36) x Not Worried* (n= 37)
Brief BESTest (%)	Falls History: 49.7 ± 23.0 No Falls History: 65.0 ± 20.7 Mean Difference= 15.3 95% CI= (5.0 to 25.6) p-value= 0.002*	High Risk: 43.7 ± 22.7 Low Risk: 66.6 ± 18.7 Mean Difference= 22.9 95% CI= (13.0 to 32.8) p-value= <0.001*	Gait Aid: 44.3 ± 19.5 No Gait Aid: 72.7 ± 16.1 Mean Difference= 28.4 95% CI= (20.1 to 36.8) p-value= <0.001*	Worried: 53.4 ± 20.9 Not Worried: 64.0 ± 23.6 Mean Difference= 10.6 95% CI= (0.2 to 21.0) p-value= 0.023*
SLS (s)	Falls History: 6.7 ± 9.4 No Falls History: 10.3 ± 9.3 Mean Difference= 3.6 95% CI= (-1.0 to 8.1) p-value= 0.004*	High Risk: 5.3 ± 6.9 Low Risk: 10.6 ± 10.1 Mean Difference= 5.3 95% CI= (1.2 to 9.4) p-value= 0.003*	Gait Aid: 5.3 ± 6.2 No Gait Aid: 12.6 ± 10.9 Mean Difference= 7.4 95% CI= (3.0 to 11.7) p-value= <0.001*	Worried: 5.8 ± 5.2 Not Worried: 10.2 ± 10.2 Mean Difference= 4.5 95% CI= (0.5 to 8.4) p-value= 0.035*
TUG (s)	Falls History: 13.1 ± 4.7 No Falls History: 12.2 ± 4.5 Mean Difference= -0.9 95% CI= (-3.1 to 1.2) p-value= 0.115	High Risk: 14.6 ± 5.5 Low Risk: 11.5 ± 3.6 Mean Difference= -3.1 95% CI= (-5.6 to -0.7) p-value= 0.004*	Gait Aid: 15.0 ± 4.6 No Gait Aid: 10.1 ± 3.0 Mean Difference= -4.9 95% CI= (-6.7 to -3.1) p-value= <0.001*	Worried: 13.2 ± 4.9 Not Worried: 12.0 ± 4.2 Mean Difference= -1.2 95% CI= (-3.4 to 0.9) p-value= 0.118
TUG-DT (s)	Falls History: 15.7 ± 5.8 No Falls History: 14.7 ± 5.7 Mean Difference= -1.1 95% CI= (-3.9 to 1.7) p-value= 0.141	High Risk: 17.7 ± 6.8 Low Risk: 13.7 ± 4.6 Mean Difference= -4.0 95% CI= (-7.2 to -0.9) p-value= 0.004*	Gait Aid: 17.6 ± 5.8 No Gait Aid: 12.7 ± 4.7 Mean Difference= -4.9 95% CI= (-7.4 to -2.3) p-value= <0.001*	Worried: 15.9 ± 6.2 Not Worried: 14.3 ± 5.3 Mean Difference= -1.6 95% CI= (-4.4 to 1.2) p-value= 0.148

Note. 95% Confidence Interval= 95% CI; * = significant at the 0.05 level (one-tailed)

Table 4. Known-Groups Validity of Balance Screening Tests for Disease-Specific Measures

Test	*Supplemental Oxygen (n= 20) x No Supplemental Oxygen (*n= 53)	*Worse Prognosis (n= 29) x Better Prognosis (*n= 36)
Brief BESTest (%)	Oxygen: 55.8 ± 17.0 No Oxygen: 59.8 ± 24.7 Mean Difference= 4.0 95% CI= (-8.0 to 16.0) p-value= 0.110	Worse Prognosis: 52.9 ± 22.3 Better Prognosis: 65.4 ± 22.3 Mean Difference= 12.5 95% CI= (1.4 to 23.6) p-value= 0.014*
SLS (s)	Oxygen: 9.0 ± 8.6 No Oxygen: 8.7 ± 9.8 Mean Difference= -0.3 95% CI= (-5.3 to 4.8) p-value= 0.290	Worse Prognosis: 8.6 ± 8.5 Better Prognosis: 10.3 ± 10.9 Mean Difference= 1.7 95% CI= (-3.3 to 6.8) p-value= 0.431
TUG (s)	Oxygen: 15.9 ± 4.7 No Oxygen: 11.3 ± 3.8 Mean Difference= -4.6 95% CI= (-6.8 to -2.5) p-value= <0.001*	Worse Prognosis: 14.4 ± 5.0 Better Prognosis: 10.8 ± 3.2 Mean Difference= -3.6 95% CI= (-5.8 to -1.4) p-value= 0.001*
TUG-DT (s)	Oxygen: 19.6 ± 6.3 No Oxygen: 13.3 ± 4.5 Mean Difference= -6.3 95% CI= (-9.4 to -3.1) p-value= <0.001*	Worse Prognosis: 17.7 ± 6.4 Better Prognosis: 12.9 ± 4.3 Mean Difference= -4.8 95% CI= (-7.7 to -2.0) p-value= 0.001*

Note. 95% Confidence Interval= 95% CI; * = significant at the 0.05 level (one-tailed)

Table 5. Ability to Identify Fall Status by Area Under the Curve (AUC) n= 73

Test	*Sensitivity/ Specificity*	*Cut-off Value*	*AUC (95% CI)*	*p-value*
Brief BESTest	80.0/55.8	64.6	0.702 (0.578 to 0.826)	0.003*
SLS	78.6/53.7	7.0	0.691 (0.560 to 0.823)	0.007*
TUG	83.3/48.8	10.2	0.583 (0.448 to 0.718)	0.230
TUG-DT	71.4/48.8	12.5	0.577 (0.440 to 0.714)	0.282

Note. 95% Confidence Interval= 95% CI; * = significant

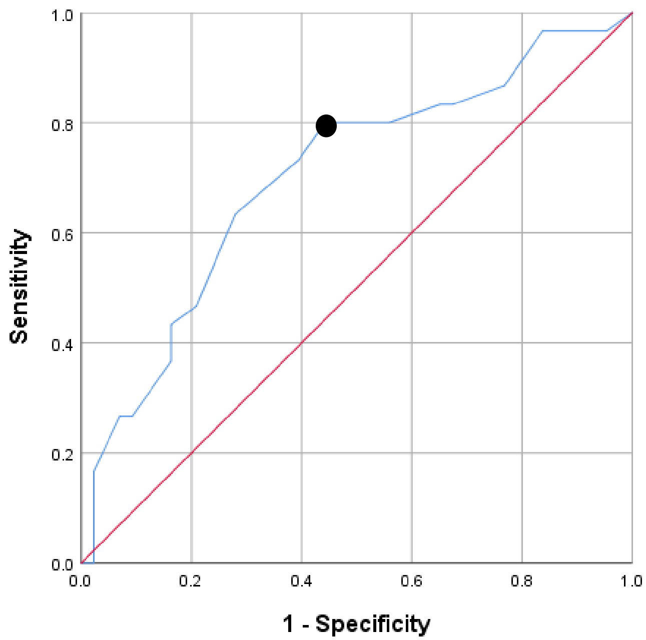

Figure 1.
Receiver Operating Characteristic (ROC) curve of the Brief BESTest for discriminating between people with COPD with and without a falls history. The optimal cut-off score (maximum sensitivity and specificity) is identified by the black dot.

2.5 Discussion

This is the first study to compare the validity of four short balance screening tests for fall risk assessment in older adults with COPD. The novel finding of this research is identifying the Brief BESTest and SLS as the two most promising balance screening tools for fall risk assessment in this population. Our results have important implications for clinical practice as older adults with COPD experience prominent balance impairments and a high risk of falls, and consequently balance testing is recommended as part of the outcomes assessment for people with COPD.[47]

Although each of the balance screening tests demonstrated moderate to strong correlations with related measures of balance and physical function, the Brief BESTest and SLS showed the strongest convergent validity with the BBS (r= 0.80 and r= 0.71, respectively), a comprehensive and robust measure of balance,[128,159,160] and the ABC scale (r= 0.61 and r= 0.52, respectively), a patient-reported measure of balance confidence.[161] It is notable that the SLS performed similarly to the Brief BESTest despite being the shortest and simplest balance screening test amongst the four that were tested. While previous studies in COPD have demonstrated the convergent validity of the Brief BESTest with the BBS and ABC scale,[153] to our knowledge, this is the first study to demonstrate convergent validity of the SLS with both the BBS and ABC scale in a COPD population.

In line with our results for convergent validity, the Brief BESTest and SLS demonstrated the most consistent ability to discriminate between groups based on fall risk status. Most importantly, they were the only two tests to discriminate between persons with and without a falls history as well as distinguish between individuals at high and low risk of falls and individuals worried and not worried about falling. Worry about falls may be related to fear of falling, which has been defined as "low perceived self-efficacy or confidence at avoiding falls"[76,77] or persistent concern about falling.[12,77] Fear of falling is an important and prevalent mental health construct in COPD[12,13] (50% prevalence in our sample) and has been strongly associated with an increased risk of falls and activity reduction in both older adult and COPD populations.[12,13,177,178] Again, it is interesting that the SLS showed one of the strongest abilities to differentiate between fall risk groups despite being the shortest test to complete. This has valuable implications for clinical practice as the SLS is an easy test to administer (minimizing room for human error) while still providing informative results to guide clinical decision-making.

Another interesting finding of this study is that the TUG was not able to discriminate between individuals with and without a falls history in COPD. This is in contrast to previous work,[16] which did demonstrate discriminative ability of the TUG for previous falls in COPD. While the subject characteristics in the previous report appear similar to our study, their sample size was much smaller (n= 39) and therefore may have been less representative of older adults with COPD. The TUG also failed to discriminate between persons worried and not worried about falling which is consistent with the results for fall status. Although the TUG is currently the most commonly recommended fall risk screening tool by clinical practice guidelines for older adults,[43,106] our results suggest that it may not be the optimal fall risk screening test for older adults with COPD. Moreover, despite the preliminary evidence supporting its psychometric properties in older adults,[119,120,129,131] the TUG-DT did not perform any better than the TUG in our study. This is consistent with previous studies comparing TUG-DT to TUG alone for fall risk assessment for older adults.[91,120] However given the established impact of dual-task performance on balance and fall risk in older adults,[90,91] there is a need for future research to confirm our findings on the value of the TUG-DT for fall risk assessment in COPD.

To our knowledge, this was the first study to concurrently examine the accuracy of multiple balance screening tests for identifying people with and without a falls history in COPD. Our results show that the Brief BESTest was the only screening test to identify individuals with a falls history with acceptable accuracy (AUC= 0.70). A possible explanation for this may be that it is longest test to administer of the four and involves six different tasks, each designed to measure a different aspect of balance control inclusive of both static and dynamic balance. Of note, the Brief BESTest includes a reactive balance task which assesses a participant's response to an unpredictable perturbation, which has been shown to have a vital role in fall avoidance.[36] In this study, the cut-off score for the Brief BESTest with the highest sensitivity and specificity for identifying persons with a fall history was 65%. This cut-off value is slightly less than that reported in another cross-sectional study,[153] which identified a cut-off of 70% on the Brief BESTest for identifying individuals with a fall history in COPD. This may be explained by differences in sample characteristics; our study included subjects with overall more severe COPD compared to the other study (mean FEV_1 47.0% vs. FEV_1 69.4%) as well as subjects with overall lower balance scores on the Brief BESTest recruited from a very different geographical region. Therefore, it makes sense that the cut-off value would be slightly more conservative in our study. Nonetheless, it is important to note that prospective studies are needed to confirm these results and to establish an optimal cut-off value for fall risk screening in COPD with a higher degree of certainty.

Although the Brief BESTest showed the highest AUC for identifying individuals at high risk of falling in this study, the accuracy of the SLS was also borderline acceptable (AUC= 0.69) and consistently demonstrated the second strongest associations with longer measures of balance and known-groups validity. This may indicate that either test can be selected for fall risk screening in

COPD depending on the setting and context. Given there is minimal constraint on time, the Brief BESTest may be most suitable to screen more comprehensively for balance impairment and to guide or monitor exercise training in COPD, such as in a rehabilitation setting. However, in a clinic setting where efficiency is the utmost priority, the SLS may be the better selection and still offer valuable information about balance deficits and fall risk status in older adults with COPD. Another consideration is the time needed to train the assessor and instruct the participant in completing the test. Again, as a result of a greater number and complexity of tasks, the Brief BESTest would require longer training time for assessors and more time to explain tasks to participants, suggesting it would be more feasible for a rehabilitation setting. Since the SLS is one simple task, this would be very straightforward for both the assessor and participant to learn.

Given the known association between balance and falls,[35,36,43,104] it is perhaps not surprising that the Brief BESTest and SLS were the two tests with the strongest measurement properties for fall risk assessment. Where both of these are “pure” evaluations of balance, the TUG and TUG-DT are broader evaluations of balance, mobility and function. Therefore, this may explain the observed differences in psychometric properties of these balance tests in a fall risk assessment context. Contrary to our results, the TUG has previously shown to discriminate between individuals with and without a falls history in COPD (AUC= 0.77),[155] but this may be attributable to a sample with less severe disease, fewer comorbidities per patient and an extremely uneven distribution of fallers and non-fallers for the ROC analysis compared to our study. Although the TUG and TUG-DT may not be preferred for fall risk screening in COPD according to our results, they may still offer valuable assessments for physical function in COPD, which is supported by our findings for known-groups validity with respect to more disease-specific outcomes.

The main limitation of this study is that it was cross-sectional. As such, we can only report on the cross-sectional validity of the balance screening tests for fall risk assessment. In addition to this, retrospective falls reporting may have been impacted by recall bias.[179] A prospective study is ongoing to confirm our results longitudinally. The generalizability of our study findings is also limited to older adults with moderate to severe COPD and receiving care for their COPD. Our analyses were sufficiently powered for construct validity, but results for concurrent validity may be limited as we did not reach the recommended target sample size for this analysis.[175] Finally, this study only evaluated four balance tests and it is possible that other balance tests would have shown better results. Nevertheless, we selected the tests with the best potential for use in clinical settings and those that had preliminary evidence supporting their measurement properties. Future work could explore the use of different balance tests for fall risk screening in COPD that were not included in this study and could extend results to a wider range of disease severity groups.

2.6 Conclusions

In summary, the Brief BESTest and SLS show the most promise as balance screening tools for fall risk assessment in older adults with COPD. Although the Brief BESTest demonstrated stronger psychometric properties between the two tests and offers a more comprehensive measure of balance, the SLS is also a feasible option in clinical practice settings with time constraints while still offering valuable information to guide clinical decision-making on fall risk assessment. Further research is needed to confirm these results using a larger sample size and prospective study design.

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Chapter 3

Discussion and Conclusions

3.1 Summary of Key Findings

Balance problems and an increased fall risk are common in people with COPD. This thesis examined the validity of four short balance tests and found that the Brief BESTest and SLS demonstrated the strongest measurement properties for fall risk screening in older adults with COPD. This work represents an important contribution to respiratory health and rehabilitation fields by addressing a critical knowledge gap in balance and falls research in older adults with COPD.

3.2 Fall Risk Assessment and Management in COPD

Despite frequently observed falls and balance problems in people with COPD,[6,11,17,19,20,23,25,30,31,33,34] to date fall risk assessment and prevention have not been included as part of the standard of care for patients with COPD. A recognized and necessary first step of any fall prevention initiative is a falls risk assessment which hinges on a test of balance or mobility.[43,46,106] For fall risk screening tests to be effective, it is important to establish population-specific psychometric properties.[107] Feasibility in terms of clinician/patient acceptability and quick administration time are also necessary requirements.[107] While all balance screening tests under investigation in this thesis were selected based on the potential to meet these criteria, the Brief BESTest and SLS fulfilled these requirements to the greatest extent. In our study, the Brief BEST and SLS demonstrated the strongest convergent validity with more extensive measures of balance as well as the most consistent discriminant ability with respect to fall risk groups compared to the other balance screening tests. A critical prerequisite to validity, excellent inter- (ICC= 0.86 to 0.97) and intra-rater (ICC= 0.82 to 0.93) reliability has been demonstrated by the Brief BESTest score in people with COPD,[114,153] as well as excellent inter- (ICC= 0.93) and intra-rater (ICC= 0.82 to 0.94) reliability in community-dwelling and institutionalized older adults.[115,137] The SLS score has shown excellent intra-rater (ICC= 0.91) reliability in COPD[154] as well as good to excellent inter- (ICC= 0.93 to 0.99) and intra-rater (ICC= 0.69 to 0.99) reliability in community-dwelling older adults.[113,117] An important next step of this research is to confirm the reliability of the balance screening tests within a single study to enable direct comparison between them. Data collection is currently ongoing to address this gap.

In addition to their cross-sectional validity, both the Brief BESTest and SLS have high acceptability in a COPD population. The Brief BESTest is frequently used in pulmonary rehabilitation and appreciated by both clinicians and patients as a result of its comprehensive assessment.[152] Similarly, the SLS is commonly used by physical therapists in Ontario[132] and as a postural control assessment tool in COPD.[76] It has also been suggested for fall risk screening in a major fall prevention algorithm for older adults (CDC).[106] These findings speak to the specific contexts that may be most conducive for administering each of these balance screening tests. Given that the Brief BESTest is a 10-minute balance test that evaluates both static and dynamic balance,[111,114-116] including reactive balance, it may be most useful in a rehabilitation setting where there are less time constraints. As shown in previous work,[19] administering the Brief BESTest allows clinicians to identify the exact areas of balance control that are impaired in the participant, which is valuable knowledge for both the clinician and patient in rehabilitation. The clinician is not only able to identify patients at high risk for falls using the cut-off score, but because the Brief BESTest includes one task from each of the six underlying balance control systems,[111] clinicians can easily use this information to guide an individualized treatment plan to improve balance and decrease fall risk for the patient. It should be noted that the assessment of reactive balance is an especially advantageous component of the Brief BESTest as there are a limited number of balance tests that incorporate this type of balance control that is widely accepted as integral to understanding fall risk.[180] In contrast, the SLS is a three-minute, single-task evaluation of static balance that may be most fitting for a busy clinic setting.[107,113] Even though it may not provide detailed information on balance impairment for the clinician and patient, it has similar psychometric properties to the Brief BESTest despite a much shorter administration time making it an equally valuable option as a fall risk screening tool. Use of the SLS as part of routine clinic visits would require minimal training, space or equipment, and would allow clinicians to maximize the number of patients they screen and as a result, allow them to identify a greater number of those at high risk for falls or in need of a fall prevention intervention.

An interesting finding from our known-groups validity analysis was that the Brief BESTest and SLS were able to discriminate between older adults with COPD who were worried and not worried about falling. Fear of falling, a similar construct to worry about falling, is strongly associated with an increased risk of falls and activity restriction in both older adults and people with COPD.[12,13,177,178] In a 12-month prospective study, increased fear of falling as measured by the Falls Efficacy Scale International was shown to predict falls in COPD.[30] Both the Brief BESTest and SLS also demonstrated the strongest correlations with a balance confidence scale

(ABC scale[161]), which is often used to assess fear of falling in COPD.[76] In a previous study,[16] the ABC scale score was able to discriminate between persons with and without a history of falls and was identified as a predictor of falls in COPD. These results suggest that it may be important to consider the role of an individual's assessment of their fear of falling and related constructs in assessing balance and fall risk in COPD, as well as specifically targeting these constructs as part of fall prevention interventions for this population.[148,149] Another finding that warrants attention includes the ability of all balance screening tests to discriminate between gait aid users and non-users in older adults with COPD. Although not extensively explored to date, use of a gait aid has been associated with an increased risk of falls in older adults[181] and may have a relationship to balance problems and a higher risk of falls in COPD.[10] Consequently, it may be important to consider the use of a gait aid as part of a fall risk assessment for patients with COPD.

While we were unable to investigate the predictive validity of the balance screening tests in COPD with prospective data, ours is one of few studies to report on the accuracy of balance tests for identifying individuals with a falls history in COPD. Similar to previous work,[153] the Brief BESTest identified older adults with a falls history in COPD with acceptable accuracy (AUC= 0.70) and this was the first study to show that the SLS also identified individuals with a falls history in COPD with similar accuracy (AUC= 0.69). Cut-off values provide clinicians the information they need to interpret a score on a balance screening test and ultimately identify those at high risk for falls who would benefit from an intervention. Although the cut-offs reported in this study require confirmation with prospective falls data, they are a useful starting point for clinicians given that falls history is an especially strong risk factor for future falls.[30,35] In our study, the optimal cut-off score for the Brief BESTest was 64% or lower for classifying older adults with COPD with high risk for falls (based on falls history). Similarly, a cut-off of 7.0 seconds or less was optimal for identifying individuals at high risk of falling with COPD on the SLS. It is important to note that these cut-off values in COPD are more conservative than those reported in older adults (e.g. the CDC recommends a 10 second cut-off on the SLS for identifying fallers[106]), emphasizing the importance of establishing population specific cut-off values where possible in order to improve the accuracy of fall risk screening. Once individuals with a high risk of falls are identified, provision of fall prevention intervention can occur.[43,46,106,107] In older adults, fall prevention interventions can reduce the rate and risk of falling by as much as 40%.[108,109] In people with COPD, there is good evidence to suggest that the addition of balance exercises to pulmonary rehabilitation can improve outcomes of balance and mobility that are associated with fall risk.[149,151] In particular, a recent narrative review by our research team[89] (please refer to Appendix A) highlighted the importance of implementing balance training for people with COPD that also incorporates functional muscle strength exercises in order to address previously identified sources of balance deficits in COPD.[19] Studies are ongoing to evaluate the efficacy of fall prevention interventions for this population.[182]

Although the TUG is a commonly recommended fall risk screening tool[106] and there is abundant evidence supporting the importance of dual-task paradigms for assessing balance and fall risk in older adults,[90-92] both the TUG and TUG-DT failed to demonstrate adequate cross-sectional validity for fall risk assessment in older adults with COPD. Unlike the Brief BESTest and SLS, the TUG[110] and TUG-DT assess both balance and mobility, with the TUG-DT also assessing the capacity to perform two tasks at once with its added cognitive element. Although balance, mobility and cognition are all inter-related to one another and to fall risk,[91,92,95-98] tests that focus on evaluating balance control as a single function, such as the Brief BESTest and SLS, may prove to be the most effective for fall risk assessment given the widely established importance of balance as a risk factor for falls.[35] Our findings support that the TUG and TUG-DT may be more suitable for other assessment purposes in individuals with COPD, such as mobility and physical function . In our study, both the TUG and TUG-DT demonstrated the strongest correlations with Chair Stands and the 6MWT out of all the balance screening tests, which makes sense given that lower leg strength and mobility are common components of these tests. The TUG and TUG-DT were notably the only two tests able to distinguish between supplemental oxygen users and non-users, and along with the Brief BESTest, discriminated between those with worse and better prognosis using the BODE index. Thus, although our results do not support the TUG and TUG-DT as optimal balance screening tools for fall risk assessment in older adults with COPD, our results do highlight their validity as measures of physical function and mobility limitation in people with COPD. In fact, this was the first study to examine the psychometric properties of the TUG-DT in people with COPD. Based on previous research demonstrating reduced dual-task performance in people with COPD,[90,145,146] and the need for balance tests to address the potential cognitive contribution to fall risk in COPD,[180] the use of dual-task testing warrants further exploration in COPD. For example, it is possible that the dual-task component of the TUG-DT was not enough of a cognitive challenge in our specific sample of older adults with COPD or that dual-task testing may be more useful for balance screening or fall risk assessment in COPD populations at greater risk for cognitive impairment, including persons on supplemental oxygen, persons with greater disease severity or persons with mild cognitive impairment.

3.3 Limitations and Next Steps

Interpretations of this thesis work need to take into account certain limitations. First of all, the study design in Chapter 2 is cross-sectional and only permitted us to determine the validity of the balance screening tests at a single point in time, although an ongoing prospective study with a larger sample size will confirm our findings longitudinally. Using retrospective falls reporting as a result of the cross-sectional design, recall bias may have occurred and underestimated the number of falls reported by our sample.[179] Secondly, our findings may not be reflective of the entire COPD population as our sample primarily included older adults with moderate to severe COPD receiving specialized treatment for their COPD. Therefore, future studies are needed to examine the performance of the balance tests in younger older adults with COPD, those with milder disease, and in general practice settings. Lastly, our sample size was adequately powered to determine convergent and known-groups validity, however it may have been limited for criterion (concurrent) validity given that 100 subjects are typically recommended for this type of analysis.[175]

3.4 Conclusions

To conclude, results of this thesis can be used to inform and guide clinical decision-making for fall risk assessment in COPD, whether in a rehabilitation or clinic setting. Our study identified that the Brief BESTest and SLS are the two most promising balance screening tests for fall risk assessment in older adults with COPD. The Brief BESTest may be most suitable for detailed screening and treatment planning in pulmonary rehabilitation, while the SLS is optimal for fall risk screening in a time-constrained clinic. The TUG and TUG-DT may prove more valuable as tests of mobility and physical function in COPD, but in this study they did not demonstrate the optimal psychometric properties for fall risk screening. Given the high burden of falls in people with COPD, there is a need to incorporate fall risk assessment as part of routine practice in this population in order to identify individuals at high risk for falls in need of intervention. Once confirmed prospectively with a larger sample size, our findings will lay the groundwork for improving fall risk assessment and prevention in people with COPD.

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Appendix A- Narrative Review

Role of Muscle Strength in Balance Assessment and Treatment in Chronic Obstructive Pulmonary Disease

Role of Muscle Strength in Balance Assessment and Treatment in Chronic Obstructive Pulmonary Disease

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ABSTRACT

Purpose: The purpose of this review is to examine the role of muscle strength in the assessment and management of balance problems among individuals with chronic obstructive pulmonary disease (COPD). Our specific aims are to: 1) synthesize the literature on the role of muscle strength in balance control among older adults; 2) provide an overview of what is known about these relationships in people with COPD; and 3) describe clinical applications of assessing and training muscle strength in the context of improving balance among individuals with COPD.

Summary of Key Points: Muscle strength is a key contributor to balance in both healthy populations and in people with COPD. Although impairments in skeletal muscle have been well studied in people with COPD, the contributions of this dysfunction to the observed balance deficits in COPD has not been as well studied to date. Furthermore, current research only supports associations between muscle strength and balance performance, and we are unable to determine cause and effect. Future research should address the impact of potential deficits in muscle power and endurance on postural control and fall risk in people with COPD.

Recommendations: Comprehensive assessment of balance in people with COPD should include an assessment of muscle strength but also cannot ignore the many other subsystems underlying balance. When targeting muscle strength as part of a balance training program, specific considerations should be given to functional lower-body and core exercises that challenge different balance systems.

Key Words: respiratory disease, skeletal muscle dysfunction, postural control

Introduction

Chronic obstructive pulmonary disease (COPD) is a progressive respiratory disease characterized by limitations in lung airflow.[1] It is a leading cause of morbidity and mortality in Canada[2] and it currently ranks as the third leading cause of death worldwide.[183] It is now well established that COPD is a complex, multisystem disease that impacts considerably more than an individual's lung function.[6-9,184,185] In particular, recent evidence has identified prominent balance impairments among those with COPD that may contribute to an increased risk of falls in this population.[10,16-19,22,23,32,33,140,184,186,187]

Balance is a complex skill that is achieved through the integration and coordination of the musculoskeletal and neural systems of the human body.[36,85,188] Muscle strength is one component that has been highlighted as a key contributor to balance problems and falls in older adults.[10,85,105,189,190] Given that skeletal muscle dysfunction is a commonly identified impairment in people with COPD,[185] it is not surprising that lower-limb muscle weakness has also been linked to balance deficits and increased fall risk in this population.[10,16,19,22]

Given the integral role that muscle strength plays in the successful maintenance of balance, and the strong associations between both muscle weakness and balance impairment with falls, there is a need to address muscle strength deficits as part of balance assessment and training for people with COPD. The purpose of this review is to examine the role of muscle strength in the assessment and management of balance problems among individuals with COPD. Our specific aims are to: 1) synthesize the literature on the role of muscle strength in balance control among older adults; 2) provide an overview of what is known about these relationships in people with

COPD; and 3) describe clinical applications of assessing and training muscle strength in the context of improving balance among individuals with COPD.

The Role of Muscle Strength in Balance Control in Healthy Individuals

Balance Control and the Role of the Musculoskeletal System

Balance, or postural control, can be defined as "the act of maintaining, achieving or restoring a state of balance during any posture or activity."[191] It consists of 2 major components: postural orientation, or the control of body alignment in relation to the environment, and postural equilibrium, or the body's ability to maintain center of mass (COM) while static or during movement.[37] Balance can be controlled either reactively when an individual responds to an external force, or proactively when an individual anticipates a postural challenge.[192] The central nervous system (CNS) is responsible for recognizing destabilizing forces and stimulating musculature to generate the right amount of force to delay the motion of COM. There are a multitude of factors that regulate balance because it is reliant on inputs from musculoskeletal, neural, vestibular, kinesthetic, motor control and cognitive systems.[192]

In relation to the musculoskeletal system, the ankle dorsiflexors, ankle plantarflexors, knee flexors, and knee extensors are the major muscle groups needed for postural stability, with primary contributors being the tibialis anterior (ankle dorsiflexion), gastrocnemius (ankle plantarflexion), hamstrings (knee flexion) and quadriceps (knee extension).[193] Each has a different role in contributing to balance maintenance. The dorsiflexors are responsible for stability during backward movements to prevent the COM from extending posteriorly beyond the base of support. The plantarflexors are in control of stabilizing the COM when there is anterior movement beyond the base of support. The knee flexors are responsible for forward sway and the knee extensors control backward sway.[193] Finally, there is a role for the hip abductors and adductors in the control of lateral stability, which may be of a particular relevance for fall risk.[36,85] Dysfunction in any of these muscle groups contributing to postural stability can lead to declines in balance performance[105] and an increased fall risk.[105]

Age-Related Changes in Muscle and Postural Control

Aging is a process that alters the properties of the neural, sensory and musculoskeletal systems,[85,105,194,195] which can further lead to balance deficits and an increased fall risk among older adults.[85,196] In terms of muscle function and normal aging, neural system alterations include a reduced activation of muscle from decreased neural drive and impairments in contractile properties, as well as a decline in the ability to develop and produce muscle force.[85,196] Age-related musculoskeletal alterations include a loss of muscle mass (sarcopenia) with preferential atrophy of type II muscle fibers, decreases in force generation, reductions in power, decreases in specific tension, and fatigability.[196]

The impact of these age-related neural and musculoskeletal changes on balance and fall risk can be observed when considering responses to external perturbations. Compensatory stepping (e.g. taking a step to avoid a fall in the event of a postural perturbation) and reaching reactions (e.g. reaching to grasp a railing during a loss of balance) are the 2 major mechanisms that counter balance perturbations and play key functional roles in fall prevention.[36,85] Both types of reactions undergo significant age-related changes that may arise from muscle dysfunction, whereby older adults demonstrate an impaired ability to control lateral stability during stepping reactions[197] and also exhibit deficits in producing reaching reactions rapidly.[36,85,197] For stepping reactions to counter loss of balance, it has been suggested that decreases in strength in specific muscle groups among older adults may result in stability challenges during the swing phase and landing.[36] In particular, substantial weakness of the hip abductors and adductors may contribute to problems maintaining lateral stability while stepping, which could increase the risk of falling laterally.[85,197] Falls due to a loss of balance laterally have been shown to be common among older adults.[104,198] In addition to this, the rate of muscle-force production may also impact stepping reactions in older adults because they may have a limited capacity to generate the fast movements required to address extreme postural challenges.[85,199] An age-related loss of fast-twitch muscle fibers and the slowing of information processing, in combination with reductions in nerve conduction velocity and neural activation may contribute to this limited capacity to generate rapid movements.[85,196]

Association Between Measures of Muscle Strength and Balance

With the recognition of the role of muscle strength in the maintenance of balance, several studies and reviews have explored the relationship between muscle strength and balance among older adults. A systematic review by Orr[105] (2010) examined cross-sectional associations between clinical measures of muscle strength or power and balance among healthy older adults, while also looking at the impact of strength training interventions on balance. Most of the included studies assessed at least one of the key muscle groups for postural control (ankle dorsiflexors, ankle plantarflexors, knee extensors and knee flexors), with knee extensors and flexors assessed most frequently. Muscle strength was most commonly measured using 1-repitition maximum on resistance machines, but other measures included isometric or isokinetic dynamometers, and functional tests (e.g. Sit-to-Stand). Muscle power was assessed using resistance machines, the

Nottingham Power Rig, and functional tests (e.g. Sit-to-Stand and Stair Climb). There was evidence for a consistent relationship between muscle strength and balance performance, where muscle strength was identified as a key contributor to postural stability. However, Orr (2010) noted that muscle weakness should not be considered the only factor contributing to balance dysfunction among older adults because only approximately half of the intervention studies reported a significant improvement in balance after strength training alone**.** In a more recent systematic review conducted by Muehlbauer et al[195] (2015), associations between measures of static, dynamic, anticipatory and reactive balance, and measures of lower-extremity muscle strength were examined in 36 studies of healthy people across the lifespan (ages 6 to 65+). Within this study, lower-extremity muscle strength was categorized into measures of maximal strength (e.g. maximal voluntary force/torque of the force-/torque-time curve), explosive force (e.g. rate of force/torque development based on slope of the force/torque-time curve) and power (e.g. jump distance, force, height and power). The study findings indicated that there were primarily small- to medium-sized correlations ($r = 0.09$-0.57) for all ages between measures of balance and lower-extremity muscle strength/power, although larger correlations ($r \geq 0.35$) were shown between measures of dynamic balance and maximal strength in older adults compared to young adults.[195]

Although there is often a focus on the role of lower-extremity muscle strength in relation to balance performance, trunk muscle strength has also been associated with aspects of static and dynamic balance and falls. A systematic review by Granacher et al[139] (2013) examined the associations between trunk muscle strength and composition, and balance, functional performance and falls among older adults. Within this review, trunk muscle strength entailed measures of both trunk extensors (back muscles) and trunk flexors (abdominal muscles), and muscle composition was defined as trunk muscle area/attenuation (e.g. fat infiltration) of the abdominal, paraspinal, quadriceps, and hamstring muscles. The authors were able to identify a low (r^2 ranging from < 1% to ≤ 18%) but significant relationship between trunk muscle strength and trunk muscle attenuation and balance, function, and falls across the 4 included studies. It was concluded that trunk strength and stability are important for achieving activities of daily living for older adults, but in particular, a stable and strong trunk may lead to more efficient use of the lower and upper extremities and in turn, better balance and function among older adults.[139] In addition to this, another systematic review conducted by Helbostad et al[200] (2010) assessed the impacts of lower extremity muscle (ankle plantarflexors and dorsiflexors, knee extensors and flexors, hip abductors and adductors) and trunk muscle (lumbar extensors) fatigue and recovery on balance and functional tasks among older adults. The authors found that fatigue of the lower extremity and trunk muscles leads to balance dysfunction and impairs performance of functional tasks.[200]

The Role of Muscle Strength in Balance Control in Chronic Obstructive Pulmonary Disease

Skeletal Muscle Dysfunction and Chronic Obstructive Pulmonary Disease

Skeletal muscle dysfunction is not only an age-related concern, but also an identified secondary impairment in COPD.[6-9,57,58,185] Skeletal muscle dysfunction in COPD results in abnormalities pertaining to structural alterations of skeletal muscle and skeletal muscle function.[8,9,57,58,185] Muscle atrophy of primarily type II fibers, decreased capillary numbers and contacts (capillary:fiber ratio), mitochondrial dysfunction, and disturbances in metabolic enzyme activity have all been identified as possible abnormalities in terms of structural alterations in skeletal muscle.[8,9,57,58,185] Reduced muscle strength and endurance have been identified as possible abnormalities in regard to skeletal muscle function.[8,9,57,58,185] These muscle abnormalities may be attributed to hypoxia, oxidative stress, low levels of anabolic hormones and growth factors, hypercapnia, inflammation, impairments in energy balance in regard to regulation of protein and nutrition, vitamin D deficiency, corticosteroid use, impairments in the renin-angiotensin system and smoking.[8,9,57,58,185]

Association Between Skeletal Muscle Dysfunction and Balance in Chronic Obstructive Pulmonary Disease

Despite the extensive literature on skeletal muscle dysfunction in people with COPD, relatively few studies have examined these abnormalities with respect to their potential impact on the extensive balance problems that have been documented in this population. In a comprehensive study of the subsystems underlying the observed balance deficits in people with COPD, it was previously noted that individuals with COPD had a unique profile of balance deficits, which included marked impairments in the biomechanics balance subsystem.[19] Balance performance in this subsystem included tasks related to strength, range of motion, and posture, and was reduced by more than 30% in people with COPD compared to age-matched controls. In this study, maximal voluntary isometric contractions of the knee extensors/flexors and ankle plantar/dorsiflexors were also measured. Small to modest associations ($r = 0.2$-0.4) were reported between knee muscle strength and clinical measures of balance such as the Berg Balance Scale, with smaller associations noted between ankle strength and balance. Although the COPD patients had reduced strength values compared to the age-matched controls, the magnitude of these associations were not unlike the ones reported in healthy populations,[105,195] suggesting that muscle weakness may be a contributor, but not solely responsible for balance problems in people with COPD.[19] Finally, people with COPD also showed a delayed stepping reaction for balance recovery in response to unexpected perturbations, despite a lack of slower muscle onset latencies (measured through electromyography [EMG]) compared with controls.[19] Therefore, skeletal muscle dysfunction may well have explained this impaired ability to generate adequate muscle power in response to perturbations; however, further studies are required to evaluate this.

Altered trunk muscle mechanics may also help explain decreased postural control in patients with COPD.[9] In quiet standing, mediolateral (ML) balance control is reliant on hip and trunk moments and movements[201] and may be more impaired than anterioposterior control in individuals with COPD.[17] It has been suggested that ML static balance is reduced in COPD as a result of a decreased contribution of trunk muscles and moments to balance.[140] This has been attributed to increased respiration demands in COPD requiring more abdominal muscle activation,[17] which could affect trunk muscle support towards postural control.[202] Using EMG to measure trunk muscle activity and the time needed to regain baseline center of pressure velocity after rapid arm movements in static standing, Smith et al[140] (2016) demonstrated that compromised balance recovery in COPD was associated with greater trunk muscle activity than was needed for breathing. Therefore, in people with COPD, balance may be compromised in part due to the double demand placed on trunk muscles in regard to postural and respiratory functions.

An additional relevant consideration in people with COPD is the impact of acute exacerbations of the disease (AECOPD) on muscle strength and balance. A recent study conducted by Oliveira et al[32] (2017) investigated balance impairments, muscle strength, and falls in the context of

AECOPD. The authors measured quadriceps strength with a handheld dynamometer and balance using both computerized posturography and the Berg Balance Scale in hospitalized patients with AECOPD, stable patients with COPD and healthy controls. Balance impairment in both individuals with AECOPD and stable COPD were associated with reduced quadricep strength (AECOPD – 28% and stable COPD – 14%). In addition, although balance performance was not different in those with AECOPD compared to stable patients, it was reported that patients with AECOPD experienced more falls in the 1 year after discharge compared to those with stable COPD. Therefore, it is possible that reduced muscle strength in people with AECOPD may further contribute to balance deficits and an increased fall risk in these patients after discharge.

Muscle Endurance, Muscle Power and Balance Control in Chronic Obstructive Pulmonary Disease

Although there is a centralized focus on the role of muscle strength in maintaining balance control in individuals with COPD,[10,19,47] it is worth noting that both muscle endurance and muscle power may have similar associations with balance.[10] To our knowledge, there are no studies that have specifically examined the contribution of deficits in muscle endurance and muscle power to balance problems and fall risk in people with COPD. However, muscle endurance is known to be reduced in individuals with COPD compared to healthy controls.[60,203] This reduction is important as it suggests increased muscle fatigability,[204] which has been linked to impaired balance control in young adults.[205] In regards to muscle power, Roig et al.[147] demonstrated a 28% decrease in lower-extremity muscle power among individuals with COPD compared to a control group using the Stair Climb Power Test, which they showed was also moderately correlated with the Timed Up and Go (TUG) test (r = -0.46). Although the TUG test was administered to measure functional performance, the test has been used to measure balance in this population and is frequently used as a measure of balance and fall risk in the elderly. [16] Further study of the link between reductions in muscle power in people with COPD and their association with balance and fall risk is warranted. Moreover, in older adults it has been suggested that muscle power may in fact play a larger role than muscle strength in postural control and fall prevention.[206,207] Muscle power not only declines earlier and at a faster rate than muscle strength with increasing age (3.5% decrease per year versus 1.5% per year, respectively),[208] but it has been shown to elicit a greater influence on postural control with measures of single-leg stand and postural sway[209] and to represent a more important predictor of functional health.[206,207] This may be attributed to the need for lower limbs to rapidly generate force in order to maintain balance during a perturbation[36,209]or to complete functional tasks.[210] In addition, muscle power may discriminate between elderly fallers and non-fallers,[207,211]as well as indicate early signs of balance deficits and fall risk among healthy older adults.[212]

Assessing and Managing Muscle Weakness as Part of Balance Assessment and Training

Balance Assessment Considerations

Balance is often referred to and thought of as a singular construct, but it has several underlying mechanisms that are important to keep in mind when assessing and treating balance impairment (Figure 1). The Systems Framework of Postural Control is a widely recognized model of balance which organizes postural control into 6 underlying systems: (1) biomechanical constraints (e.g. strength and coordination), (2) movement strategies (e.g. stepping reactions), (3) sensory strategies (e.g. vision, vestibular, and somateosensory), (4) orientation in space, (5) control of dynamics (e.g. gait), and (6) cognitive processing (e.g. attention).[37] In particular, strength is included under “biomechanical constraints.”[37] In a scoping review of 66 different balance measures, Sibley et al[180] (2015) found that all 66 measures included tasks that evaluated muscle strength and coordination to some degree, whereas other systems such as movement strategies and cognitive processing were less frequently evaluated. It is not surprising, therefore, that in a study of balance assessment practices among physiotherapists, more than 80% of respondents reported regularly assessing underlying motor systems such as strength when evaluating balance.[132] Although muscle strength is an important component of balance, measures that assess multiple components are necessary to identify the underlying impairments that can be targeted by interventions. The Balance Evaluation Systems Test (BESTest) is the one standardized clinical measure that has been shown to evaluate all aspects of balance.[180] Other measures such as the Clinical Gait and Balance Scale, Fullerton Advanced Balance Scale, Mini-BESTest, and Unified Balance Scale are fairly comprehensive, but most measures identified (52%) evaluated a third or fewer components of balance.[180] The Clinical Gait and Balance Scale and The Unified Balance Scale do not cover cognitive influences and verticality components of balance, respectively,[180] and both of these measures have only been used in neurological populations to our knowledge. The Fullerton Advanced Balance Scale and the Mini-BESTest are missing the verticality, and functional stability limits components of balance, respectively,[180] and both have been used in general populations of older adults.[59,213] Despite these findings, the measures most often used in clinical practice are the single-leg stance test (SLS), the BBS, and the TUG,[132] which, with the exception of the BBS, measure less than half of the underlying balance systems.

Assessing Balance in People with Chronic Obstructive Pulmonary Disease

In the assessment of balance in people with COPD, the most commonly used measures in the literature are the BBS, the short physical performance battery (SPPB), SLS and functional reach test (FRT).[76] The FRT and SPPB have criterion validity for predicting increased risk of disability in people with COPD, and the BBS is responsive to pulmonary rehabilitation.[76] The measures with the most comprehensive evidence for their psychometric properties are the BBS and BESTest, but, consistent with general clinical practice, the BESTest is less frequently used with people with COPD,[76] likely owing in part to its more recent development and also its longer administration time (45 minutes vs 30 minutes for BBS). Of note, the minimal clinically important difference has been established for the BBS (5 points) and BESTest (13 points) in patients with COPD undergoing pulmonary rehabilitation.[214] Although all of these measures provide clinicians with an observation of tasks that provide insight into any muscle strength deficits that may be contributing to balance impairment, only the BESTest has a section explicitly devoted to biomechanical tasks and an associated score solely for this subsystem. Thus, in considering selection of the optimal balance measure, if a comprehensive test to guide exercise prescription is preferred, the BESTest would be the ideal choice if time allows. In terms of shorter balance screening tests to determine the need for further evaluation and risk of falls, there is currently little evidence to guide test selection in COPD. In older adults, tests such as the SLS and TUG are often endorsed for this purpose.[215] The SLS has been shown to have excellent reliability,[117] to be predictive of injurious falls among older women,[123,134,135] and to discriminate among those with stable COPD, those with AECOPD, and age-matched controls, as well as among those with varying falls history.[25] The TUG has been shown to discriminate between fallers and non-fallers in COPD[16] and has demonstrated reliability and predictive validity for falls in a few different studies with older adults, but with limited diagnostic accuracy in some populations.[126,128] The Centers for Disease Control recommends using tests of standing balance and the TUG as tools for falls screening and prevention algorithm for older adults.[106]

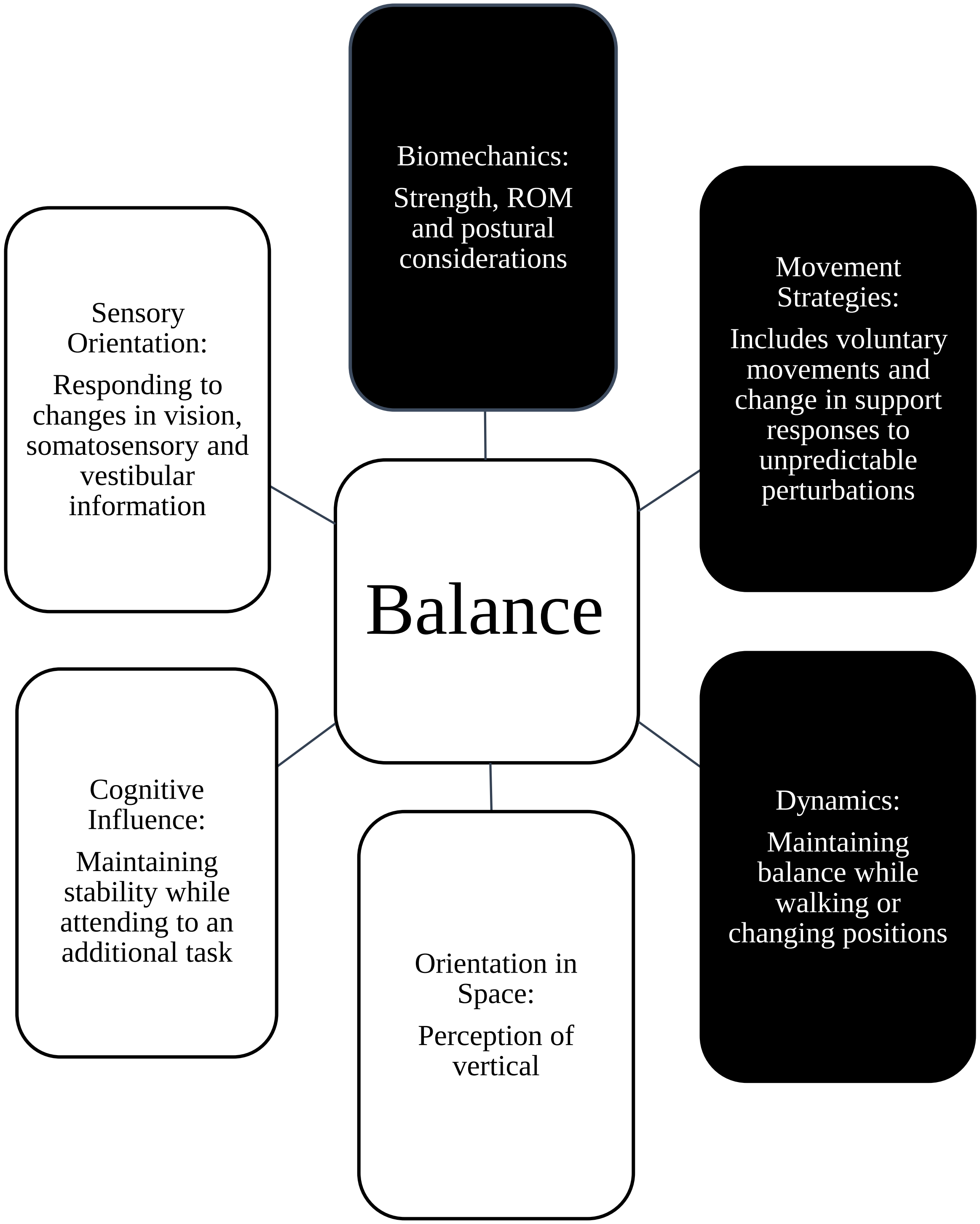

Figure 1. Components of balance. Adapted from Horak et al. *Age and Ageing* 2006, *Physical Therapy* 2009 & Sibley et al. (2015); Beauchamp et al. (2012) demonstrated that all components of balance are impaired in people with COPD. The shaded boxes represent the components of balance that were markedly impaired (biomechanics, movement strategies and dynamics). COPD, chronic obstructive pulmonary disease

Table 1. Functional Strengthening Exercises Typically Included as Part of Balance Training for Fall Reduction

Exercise	Balance-Related Progression Examples[a]
Toe and calf raises	Begin with arm support, progress to light finger support and then no support, add head turns 10 reps, 1 set
Step-ups	Begin with arm support, progress to no arm support, increase speed, add arm movements 10 reps (5 on each leg), 1 set
Lateral step-ups	Increase speed and add arm movement 10 reps (5 on each leg), 1 set
Side-stepping with theraband	Begin with arm support, progress to no support, add secondary cognitive task (e.g. name words that start with “w”) 10 steps, 4 sets
Chair rise	Start in chair with arms, progress to chair with no arms, vary speeds and “stop” midtask, add unstable cushion, and add weighted ball 5 reps, 1 set
Walk on toes and walk on heels	Begin with arm support, progress to light finger support and then no support, and add secondary cognitive task (e.g. count backward by threes) 10 steps, 4 sets
Core strengthening on ball	Practice weight shifts, add toe claps, close eyes, add knee raises, and add arm movement 10 reps, 1 set (close eyes for 10 s)

[a]Repetitions/sets for balance-related progression are based on Otago Exercise Programme guidelines.[216] However, these guidelines are only suggested starting points for patients, and exercise prescription should be individualized for each patient.

Balance Treatment Considerations

Given the impairments in skeletal muscle seen in people with COPD and the contribution of muscle weakness to balance impairment, it is clear that muscle strength should be assessed as part of a comprehensive balance assessment and any weakness treated as a part of an exercise program. Training for muscle strength traditionally includes resistance training with free weights, pulleys, exercise bands or machines that focuses on specific muscles or muscle groups. On the other hand, strength training for balance typically focuses on lower-extremity muscles and involves more functional exercises such as leg press, hamstring curls, knee extensions, lunges, squats and calf raises. There is heterogeneity in the programs that have been evaluated in the literature for their effect on balance in the elderly with program durations ranging from 10 weeks to 1 year, session durations ranging from 45 to 90 minutes and intensities ranging from 40% to 85% of 1 repetition maximum.[217-223] Despite showing improvements in TUG,[218,220] FRT,[220,222] tandem walk test,[222] chair rise,[220] and SLS[220] after resistance training, as highlighted previously in this article, these trials found inconsistent results for the effect of strength training on balance.[217,219,221-223] There are benefits of strength training, but in isolation, exercise focused only on strength is not likely to impact balance or falls; only 22% of studies in a systematic review provided support for resistance training to improve balance.[224] The most effective programs for older adults are multicomponent programs that include an aspect of training that challenges balance.[225] In particular, balance training program durations of 11 to 12 weeks with training frequencies of 3 sessions per week and session durations of 31 to 45 minutes have been found to be effective for improving fall risk.[37]

Training Balance and Muscle Strength in People with Chronic Obstructive Pulmonary Disease

Several studies have explored changes in balance in people with COPD, which occur as a result of participation in standard pulmonary rehabilitation programs as well as changes that occur as a result of targeted balance training with or without pulmonary rehabilitation. Although conventional pulmonary rehabilitation has been shown to improve balance to a small degree, these improvements have not been shown to be clinically significant.[148,149] With targeted and comprehensive balance training, large and clinically meaningful improvements in BBS, BESTest, chair rise, and TUG have been achieved in people with COPD.[149,151,152] These effective balance training programs did include functional strength training as part of the balance training protocols to impact the biomechanical constraints system[149,151] that has been shown to be one of the areas of particular impairment in people with COPD.[19] Examples of functional strength training that can be incorporated into a balance training program for people with COPD can be found in Table 1. These exercises can be progressed to allow for sufficient overload by increasing the number of repetitions and resistance, and progression of balance difficulty can be achieved by decreasing upper-extremity support, increasing speed of movement, changing sensory-information, adding internal balance perturbations or adding a secondary cognitive task. These exercises should be tailored to each individual's abilities and progressed as needed to ensure sufficient and ongoing challenge to both balance and strength.

Conclusion

In summary, we have described how muscle strength is a key contributor to balance in both healthy populations and in people with COPD. While impairments in skeletal muscle have been well studied in people with COPD, the contributions of this dysfunction to the observed balance deficits in COPD has not been as well studied to date. Furthermore, current research only supports associations between muscle strength and balance performance, and we are unable to determine cause and effect. In addition, the implications of potential deficits in muscle power and endurance for postural control and fall risk in people with COPD requires further study. Comprehensive assessment of balance in people with COPD should include an assessment of muscle strength but also cannot ignore the many other subsystems underlying balance. When targeting muscle strength as part of a balance training program, specific considerations should be given to functional lower-body and trunk exercises that include a challenge to different balance systems.

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Appendix B- Psychometric Properties of Balance Screening Tests for Fall Risk Assessment in COPD

	RELIABILITY		**VALIDITY**		
Balance Screening Test	Inter-rater Reliability	Intra-rater Reliability	Convergent Validity	Known-Groups Validity	Criterion Validity
Brief Balance Evaluation Systems Test (Brief BESTest)	Jacome et al. (2016) n=28 Elderly with mild/moderate/ severe COPD ICC=0.97 Leung et al. (2019) n=30 Elderly with moderate to severe COPD ICC=0.86	Jacome et al. (2016) n=28 Elderly with mild/moderate/ severe COPD ICC=0.82 Leung et al. (2019) n=30 Elderly with moderate to severe COPD ICC=0.93	Jacome et al. (2016) n=46 Elderly with mild/moderate/ severe COPD BBS: r=0.73-0.90* ABC scale: r=0.53*	Jacome et al. (2016) n=46 Elderly with mild/moderate/ severe COPD Discriminated between fallers and non-fallers based on falls history	Jacome et al. (2016) n=46 Elderly with mild/moderate/ severe COPD Discriminated between fallers and non-fallers (falls history) with acceptable accuracy (AUC=0.78)
Single-Leg Stance (SLS)		Mkacher et al. (2017) n=60 Elderly males with mild-severe COPD ICC=0.91		Crisan et al. (2015) n=29 Elderly with stable COPD n=17 Elderly with AECOPD n=17 Healthy elderly Discriminated between stable COPD, AECOPD and age-matched controls. Discriminated between non-fallers, one-time fallers and recurrent fallers based on falls history in stable COPD and AECOPD	
Timed Up and Go (TUG)	Al Haddad et al. (2016) n=13 Elderly with mild/moderate/ severe COPD ICC=0.99 Marques et al. (2016) n=60 Community-dwelling elderly with mild to moderate COPD ICC=0.997	Mesquita et al. (2013) n=95 Elderly with advanced COPD ICC=0.85 (between 1st and 2nd trails in same day) ICC=0.98 (between 2nd and 3rd trials in same day)	Reynaud et al. (2018) n=50 Stable, mild to severe COPD patients BBS: -0.92	Beauchamp et al. (2009) n=39 Elderly with moderate COPD Discriminated between fallers and non-fallers based on falls history as well as supplemental O2 users and non-users	Al Haddad et al. (2016) n=119 Elderly with mild/moderate/ severe COPD Discriminated between fallers and non-fallers in COPD (falls history) with acceptable accuracy (AUC=0.77)

		Al Haddad et al. (2016) n=22 Elderly with mild/moderate/ severe COPD ICC=0.96 Marques et al. (2016) n=41 Community-dwelling elderly with mild to moderate COPD ICC=0.92 Mkacher et al. (2017) n=60 Elderly males with mild to severe COPD ICC=0.91		Crisan et al. (2015) n=29 Elderly with stable COPD n=17 Elderly with AECOPD n=17 Healthy elderly Discriminated between stable COPD, AECOPD and age-matched controls. Discriminated between non-fallers, one-time fallers and recurrent fallers based on falls history in stable COPD and AECOPD Al Haddad et al. (2016) n=119 Elderly with mild/moderate/ severe COPD n=58 Healthy elderly Discriminated between fallers and non-fallers in COPD based on falls history	
Timed Up and Go Dual-Task (TUG-DT)					

Note. ICC (2,1): excellent = > 0.75, moderate-to-good = 0.40-0.75, poor = < 0.40[226]; BBS: Berg Balance Scale; ABC Scale: Activities-specific Balance Confidence Scale; AECOPD: Acute Exacerbation of COPD; O2: Oxygen; *=significant