The Associations Between Muscle Function, Physical Performance and Fall Injuries in Older Adults

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Mary E. Winger, PhD

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Abstract

Background: Weight-bearing measures of lower-extremity muscle mechanical function may be more strongly related to physical performance and fall injury than non-weight-bearing measures in older adults. However, these relationships are not well-described since past studies have typically not included multiple muscle function and physical performance measures, or non-fracture fall injuries.

Objectives: This dissertation examined associations of (1) multiple muscle function measures (lower-extremity muscle power and strength, and grip strength) with physical performance, (2) novel jump test measures (jump power, velocity and force) and grip strength with physical performance, and (3) baseline leg power and grip strength with incident fall injuries (non-fracture and fractures).

Methods: Study populations included community-dwelling older adults from the (1) Developmental Epidemiologic Cohort Study (N=68; age=78.5±5.5 years; 57% women), (2) Osteoporotic Fractures in Men (MrOS) Study clinic visit 4 (N=1,242 age=84±4 years), and (3) MrOS baseline clinic visit with fall injury follow-up data (N=5,994; age=73.7±5.9 years). Multiple regression analyses with standardized βs were applied to objectives 1 and 2; generalized estimating equations with unstructured correlation were applied to objective 3.

Results: First, jump power and grip strength had higher magnitudes of association with faster gait speed than the other power or strength measures, a magnitude of association with faster

400m walk time that was similar to Keiser power and higher than other power and strength measures, and a lower magnitude of association with chair stands speed than any other power or strength measures. Secondly, lower power and velocity were associated with slower gait speed, longer 400m walk time and slower chair stands speed, whereas force and grip strength were more weakly associated with physical performance. Finally, both lower leg power and grip strength were associated with increased fall injury risk.

Conclusion: These findings suggest that muscle function impairments are related to physical performance, including mobility, and fall injuries in older adults. Future studies should examine longitudinal associations of muscle function changes with changes in geriatric outcomes related to physical performance, mobility and falls. The public health relevance of current findings is that identifying potential earlier muscle function predictors of disability may inform prevention efforts that would ultimately reduce disability incidence.

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1.0 Introduction

1.1 Aging Muscle Physiology in Older Adults

Muscle structure and function decline with aging, starting as early as the fourth decade of life. Muscle fibers are categorized as type 1 (slow twitch) or type 2 (fast twitch) fibers. Aging is associated with an increase in the clustering of type 1 fibers and a decrease in area of type 2 fibers.[1] The aging process also reduces the size, elasticity and power of all muscle tissues, leading to the inability to recover from muscular injuries and lower exercise tolerance. Muscle fibers loss of ATP, glycogen reserve and myoglobin and skeletal muscle fibers become smaller in diameter primarily due to a decrease in the number of myofibrils, causing a reduction in muscle strength and endurance and more rapid fatigue.[2] Fibrosis, a process by which muscles develop increasing amounts of fibrous connective tissue, makes muscles lose elasticity[2]. With age, the ability to recover from injuries decreases due to impaired repair capabilities of the muscle.[2] Specifically, the number of satellite cells for repair decreases and fibrous tissue increases, leading to the formation of scar tissue from an injury because of inadequate repair.[2] Finally, muscles tolerance for exercise also decreases and can result in fatigue of muscles.[2] Physiologic changes in muscle that occur with aging lead to decreased muscle function and may result in poor health outcomes, such as worse physical function or increased risk for falls and fall injuries in older adults.

Age-related muscle loss has been used to define sarcopenia. Multiple definitions exist and include varying cut-points for appendicular lean mass (ALM), ALM and grip strength, or ALM, grip strength and gait speed. In the New Mexico Aging Process study, Baumgartner et al. defined sarcopenia as ALM/ht^2 that was 2 standard deviations below the mean of a healthy young adult population.[3] In the Health, Aging and Body Composition (Health ABC) Study, Newman et al. defined sarcopenia as the 20th percentile of the residuals distribution from linear regression of ALM on height and fat mass.[4] The European working group definition included height-corrected ALM, grip strength and gait speed[5]. The ALM/ht^2 cut-point was <7.26 kg/m^2 for men and <5.45 kg/m^2 for women. The grip strength cut-point was <30 kg for men and <20 kg for women. The gait speed cut-point was ≤0.8 m/s. The international working group definition included height-corrected ALM and gait speed.[6] The ALM/ht^2 cut-point was ≤7.23 kg/m^2 for men and ≤5.67 kg/m^2 for women. The gait speed cut-point was <1.0 m/s. The Foundation of the NIH (FNIH) definition included ALM corrected for body mass index (BMI) and grip strength.[7] The ALM/BMI cut-point was <0.789 for men and <0.512 for women. The grip strength cut-point was <26 kg for men and <16 kg for women. Though a widely accepted definition of sarcopenia is lacking, the prevalence of sarcopenia (Baumgartner definition) in adults aged 64-93 years was 23% in women and 27% in men, with higher rates in adults ≥80 years old (31% in women; 53% in men).[8] Age-related declines in muscle strength are only partially explained by declines in muscle mass.[9,10] Across all race and sex groups, the annual declines in strength were three times greater than muscle mass declines.[10]

Additionally, past cross-sectional research has also found that power and strength are lower at older ages compared to younger ages in studies.[11-16] Skeletal muscle mass declines have been shown to be 2 times greater in lower limbs compared to upper limbs.[17] Loss of muscle, especially in the lower extremities, is important in older adults as muscles in the lower body are required for most activities (i.e., walking, climbing stairs). Additionally, the rate of lower limb skeletal muscle loss was more than twice the rate of upper limb muscle loss in an MRI study of adults aged 18-88 (43% women), with noticeable decline in skeletal muscle after age 45 years.[17] Defining risk factors and health consequences of age-related muscle deterioration are crucial for successful aging and as the age of the population continues to increase, this has become an important public health issue.

1.2 Conceptual Model

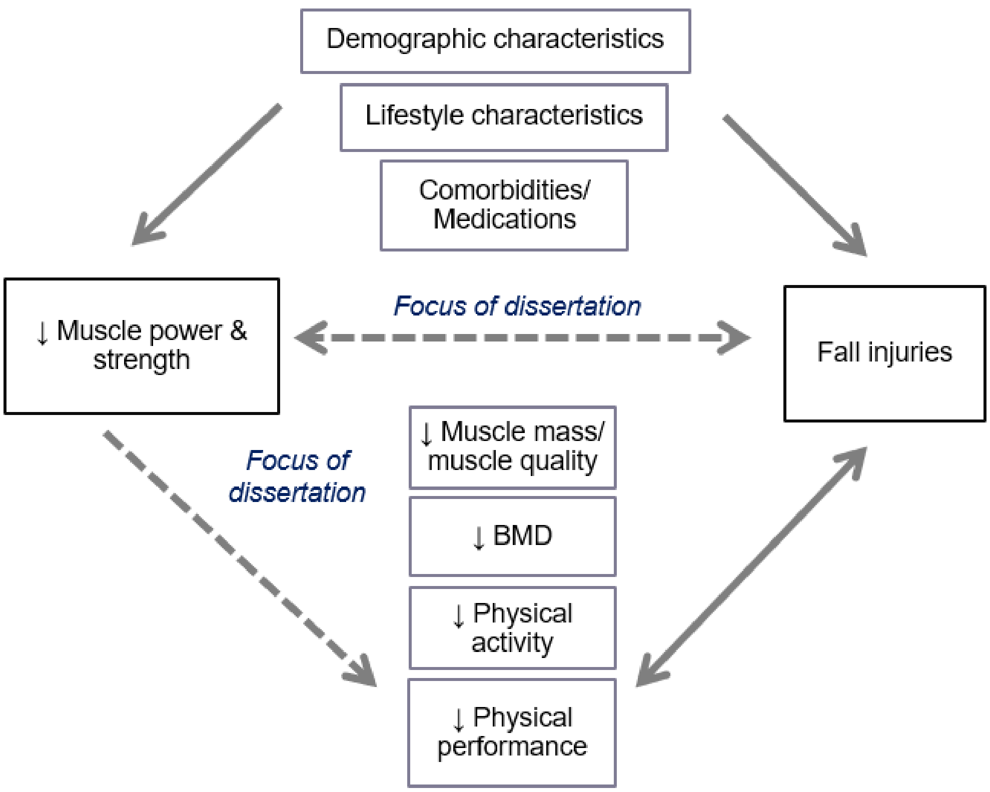

Figure 1. Muscle power and strength, physical performance and fall injury conceptual model

The conceptual model (Figure 1) represents future directions based on the review of muscle function, physical performance and falls and fall injuries in older adults. The dashed arrows indicate the relationships to be studied.

The boxes with arrows leading to muscle power and strength and fall injuries represent risk factors to be considered as confounding factors.

1.3 Basic Epidemiology of Falls and Fall Injuries

Falls are the leading cause of both fatal and nonfatal injuries in older adults[18] and are a critical public health concern for the aging population. Approximately 25-35% of older adults self-report at least one fall annually.[19-21] In The Osteoporotic Fractures in Men (MrOS) Study, a multi-center study including community-dwelling men ≥ 65 years, 21% of men self-reported ≥ 1 fall in the past 12 months.[22,23] In the Health Aging and Body Composition (Health ABC) study, 24% of women and 18% of men self-reported ≥1 fall in the year prior to the baseline exam.[24] The 2014 CDC Web-based Injury Statistics Query and Reporting System (WISQARS) data indicates that 2.3 million nonfatal fall injuries were treated in emergency departments and over 660,000 of these patients were hospitalized.[25] In the 2014 Behavioral Risk Factor Surveillance System (BRFSS) survey, and 37.5% reported ≥1 fall that required medical treatment or restricted activity for at least 1 day. Risk factors for falls and fall injuries may differ. Additionally, though risk profiles may vary across injury types (sprains/strains, contusions/abrasions, fractures) though non-fracture fall injuries have not been well studied in older adults.

Falls and fall injuries increase with age and vary by sex to race. In the 2006 Behavioral Risk Factor Surveillance System (BRFSS) survey, falls were self-reported and defined as unintentionally coming to rest on the ground or another lower level within the past 3 months. Those who reported any fall were asked if the injury limited regular activities for at least a day or required a doctor visit. Of older adults completing the BRFSS survey, 16% (approximately 5.8 million) of all older adults self-reported a fall in the past 3 months and 13% of adults aged 65-69 years, 14% of adults aged 70-74 years, 16% of adults aged 75-79 years and 21% of adults aged 80+ years self-reported a fall or fall-related injury in the past 3 months.[26] Additionally, no sex differences were found in self-reported falls in the past 3 months (15% in men; 16% in women), though women reported more injuries from falls (36%) than men (25%).[26] Falls have been shown to vary by race. Non-Hispanic whites were 23-40% more likely to fall than African Americans.[24,27] In the BRFSS survey, American Indians/Alaska Natives had the highest percentage of self-reported falls (28%) and Hispanics had the highest percentage of self-reported fall injuries (41%). Importantly, multiple races/ethnicities have not been included in large epidemiological studies of fall risk factors in older adults. The risk factors for fall injuries may also vary from those associated with falls and may be different based on type of fall injury (non-fracture vs. fracture). Considering these demographic confounders is essential in future studies of falls and fall injuries in older adults since these may account for some of the association between certain predictors and falls and fall injuries.

Health care costs and utilization are higher among older adults with fall injuries. Annual Medicare costs for falls was an estimated $31.3 billion.[28] A study of older adults living in a nursing home[29], a fall was defined as "an unintentional loss of balance causing unexpected contact with the ground or floor" and categorized as: no injury (30%); psychological/functional injury only (20%); abrasion/contusion (20%); laceration/hematoma (17.5%); nonsurgical fracture and orthopedic injury (5.5%); fracture requiring casting (2.3%); fracture requiring surgery (2.3%); intracranial injury (1.5%); and multiple injuries (1%). A fall with multiple injuries was the costliest (1-year post-fall cost of $22,368 USD). A fall with no injury was the least costly (1-year post-fall cost of $319 USD per event), though was higher relative to those who did not experience a fall. In a study of non-institutionalized adults aged 72 years and older[30], fall events were defined as "unintentional changes in position to the floor or ground" and were collected by monthly fall calendars over 1 year. Participants with falls (or who failed to return postcards) were contacted directly and hospital and emergency room surveillance was used to verify fall status. Proxies were used for participants that seemed confused, unreliable or could not be reached after five attempts in a week. Falls were categorized as: 1 fall without serious injury; 2+ falls without serious injury; and ≥1 fall with serious injury, including all fractures and joint dislocations, head injuries resulting in loss of consciousness and hospitalization, internal injuries resulting in hospitalization, and joint injuries resulting in hospitalization or in decreased mobility or activity for ≥3 days. Injuries were verified by combining hospital records, emergency department records and self-report. Costs and utilization for fallers were calculated for 1 year after the first fall. Costs and utilization for non-fallers were calculated for 1 year from baseline interview. Compared to non-fallers, total health care costs 1-year post-fall were $2,500 USD higher for those with 1 fall without serious injury, $11,900 USD higher for those with 2+ falls without serious injury and $19,440 USD higher for those with ≥1 fall with serious injury. In both studies, falls were associated with increased health care costs, and costs were highest with increased fall frequency and severity. However, health care costs in the year prior to baseline were not provided and we cannot determine if the fall event caused an increase in health care costs or if fallers had higher costs prior to the fall. Determining the difference in healthcare costs from pre-fall event to post-fall event is important in determining if falls and fall injuries result in higher individual health care costs. Additionally, evaluating potential modifiable risk factors of falls and fall injuries could reduce health care costs associated with falling.

The older adult population is expected to increase 55% by 2030. Falls and fall injures will also increase unless effective interventions are implemented nationwide.[18] Risk factors for falls and fall injuries should be studied in this rapidly increasing older adult population. Establishing fall and fall injury risk profiles for older adults may inform the targeted prevention efforts that must be created for these at-risk populations.

2.0 Methods/Equipment to Assess Lower-Extremity Muscle Function in Older Adults

Lower-extremity muscle function is essential for performing everyday activities, such as standing up from a chair, walking and climbing stairs. Muscle function is the ability of the muscles to generate mechanical power (Watts) and is defined as the product of contractile force (Newton) and contraction velocity (meters/second).[31,32] Both muscle strength and power are measures of muscle function and can be assessed in several ways. Muscle strength tests (e.g., grip strength and knee extensor strength) typically require a 1-repition maximal muscle contraction to create a peak force.[33] Power tests (e.g., chair rise and countermovement jump tests) require a generation of as much force as possible, as quickly as possible, and is usually corrected for body-weight (Watts/kg).[33] A single gold standard method for measuring muscle function does not exist and the correlation estimates used to assess validity may be influenced by measurement errors of the reference method. In addition, the protocols for each measure are inconsistent across studies of older adults, making it difficult to compare validity and reliability across studies. The method chosen to measure muscle function may depend highly on the characteristics of the population being studied, such as functional ability or comorbid conditions, and the outcomes being assessed. Therefore, the strengths and limitations, as well as the reliability and validity of muscle strength and power measures must be carefully considered in the evaluation of studies of older adults that include muscle function tests.

2.1 Hand-Held Dynamometer Grip Strength

Hand grip strength is a measure of upper-extremity strength. Hand grip strength using a dynamometer requires an isometric muscle contraction where maximum force is applied to the dynamometer without movement of the joint.[34] Grip strength has been measured using a variety of instruments classified as hydraulic, pneumatic, mechanical, or strain, each with different key features.[35] Hydraulic hand held dynamometers (e.g., Jamar, Asimow Engineering, Santa Fe Springs, CA, USA)[36] have handles that can be adjusted to five different positions (2.5, 3.8, 5.1, 6.4 and 7.6 cm apart) and strength in kilograms (kg) or pounds of force is read from a gauge based on a sealed hydraulic system. Pneumatic devices (e.g., Martin Vigorimeter, Elmed Inc., Addison, IL, USA)[37] measure grip pressure in millimeters of mercury (mmHg) or pounds per square inch (psi; lb/in^2) through compression of an air-filled compartment, such as a bag or bulb. Mechanical instruments (e.g. Harpenden dynamometer, British Indicators Ltd, England)[38] measure grip strength in kg or pounds of force as the amount of tension produced in a spring. Strain dynamometers (e.g., Isometric Strength Testing Unit)[39] measure strength in Newton of force (N) by applying strain to a wire and determining the variation in electrical resistance of a length of wire. Though many devices exist to measure grip strength, the Jamar hydraulic hand-held dynamometer is the most commonly used equipment to measure grip strength

Results from hand grip strength measures may differ depending on equipment used and measurement error may bias results. In community-dwelling older adults ≥65years, where mean differences in hand grip strength were non-significant from baseline to 12 weeks (8.5 N in right hand; 3.4 N in left hand), the reliability of the Jamar hydraulic hand held dynamometer was assessed with reliability defined as excellent (ICC≥0.90); good (ICC 0.75-0.90) is good, moderate (ICC 0.50 to 0.75) and poor (ICC<0.50). The Jamar dynamometer had excellent reliability in the right (ICC= 0.91) and left (ICC=0.95) hands.[40] Another study of older adults using the Jamar dynamometer found good reliability with a mean percentage difference between the first and second tests of 10.1% (SD=7.1%) for the dynamometer.[34] These studies did not adjust or account for any participant characteristics, such as pain, which may affect the results from this measure in older adults with arthritis or hand pain.

Hydraulic hand-held dynamometers used to measure grip strength are reliable, portable, inexpensive, and a large amount of normative data exists for strength measures using these devices, however they can cause pain for those with weak joints. Additionally, the equipment can develop slow leaks and hysteresis (the measure may depend on previous strength measures), leading to incorrect strength measures.[35] The pneumatic dynamometers are less difficult for those with weak or painful joints, though grip pressure and not grip strength is measured, so comparing or interpreting results across studies is challenging due to different units of measure. Mechanical dynamometers are not typically used due to the limited reproducibility because of difficulties in exactly replicating grip position and calibration of the device. Strain dynamometers are not subject to leaks though can be very expensive and heavy and therefore not feasible in large epidemiologic studies. Overall, measuring grip strength/pressure may depend on the surface area over which the force is applied, so hand size can influence the measurement such that, when applying the same force, a person with a small hand will record a higher grip strength/pressure than one with a large hand. Similarly, those with larger overall body size may record higher strength/pressure compared to those of smaller body size. Normalizing the strength measures by body weight may help account for these differences in hand/body size.

2.2 Leg Extension

2.2.1 Keiser Pneumatic Leg Press

Figure 2. The Keiser pneumatic resistance seated leg press machine

(Keiser Sports Health Equipment, Fresno, CA)

The Keiser pneumatic resistance seated leg press machine (Keiser Sports Health Equipment, Fresno, CA) measures the strength and power of the lower limb extensor muscles. Participants sit in a seat that can be adjusted to align the hips and knees and place each foot on a pedal. The foot pedals can move independently to allow testing of one leg or can be connected to allow testing of both legs. Strength from the Keiser leg press machine is a measure of isokinetic strength and can be used in studies of older adults.

Various protocols have been used for measuring leg strength and power. Participants are instructed to perform a single or double leg extension as fast as possible through a full range of motion in order to establish maximum strength, referred to as the 1-repition maximum (1RM). Though one study found that maximum power during the double leg press occurred between 56-78% of the one repetition maximum (1RM)[41], power testing is completed at single or multiple percentages of the 1RM with maximum power defined differently across studies. In the MOBILIZE Boston Study, participants performed 8-12 double leg presses in order to determine the 1RM.[42] Power testing was then performed at 40% of the 1RM and the highest of 5 repetitions at 40% 1RM was recorded as the maximal double leg press power. Amount of rest time between the 1RM and power testing was not provided. In another study that included N=40 older adults with mild to moderate Parkinson's Disease, the 1RM was defined using 5-10 total presses for each leg, totaling 10-20 presses[43] and after 30 minutes of rest, power was measured at 8 different percentages of the 1RM in ascending order (20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%). In community-dwelling older adults aged ≥70 years, testing included determining the initial resistance as 20% of body weight with 3 unilateral warm-up trials and increases of 10% of body weight until average power began to decrease, at which point the resistance was increased by 5% of body weight.[44] The 1RM was defined as the highest resistance (N) and peak power was calculated for each leg with 20 total leg presses at 40%, 50%, 60%, and 70% of body weight. The amount of time between establishing the 1RM and the power testing was not defined. A standard protocol for establishing the 1RM and power testing with the Keiser equipment has not been developed and these differences could affect the strength and power measures. Both the total number of leg presses during establishment of the 1RM and power testing, and inadequate rest time between the 1RM and power testing, may result in muscle fatigue during testing. Alternatively, Keiser leg strength may not be feasible in large studies of older adults if testing is long due to protocols with longer rest periods after 1RM is determined. Frail older adults may not be able to complete testing to due potential difficulty getting into the seat and fatigue, which will exclude older adults who are important to be included in studies of muscle function.

The validity and reliability of Keiser power and strength has been assessed in older adults. Keiser strength and power was validated against the 1RM achieved on the double leg press (R^2=0.584, p< 0.001), the vertical jump test (R^2=0.538, p<0.004) and maximal power (R^2=0.299, P<0.015) in N=19 older women.[41] Average power (W) and resistance (N) from the Keiser leg press were highly reliable (inter- and intra-tester reliability r=0.972 and 0.991, respectively) in N=43 adults aged 78±5 years (65% women; 98% white)[44]. However, because a gold standard measure for lower-extremity muscle function does not exist, these validity estimates are only for Keiser vs. power from jumping tests.

2.2.2 Nottingham Power Rig

Figure 3. Representation of leg extensor power rig

The Nottingham power rig can be used to measure leg extensor power (Figure 2). The equipment consists of a seat and a footplate connected through a lever and chain to a flywheel that is pushed by participants.[45] The two footplates are connected across the bottom of the power rig so that either leg may be tested. The footplates are covered with ribbed rubber to prevent slipping. The seat position is adjusted so that when the footplate is fully depressed, the leg is fully extended. Extensor muscles of the knee, hip and ankle all contribute when performing the leg extension. Participants practice sub-maximal pushes and then perform the maximal effort pushes (5-10) with arms folded across the chest and the other foot resting on the floor. Verbal encouragements are usually given, as well as rest periods between leg presses. Data collection begins with the movement of the pedal and plots of rotational velocity, time and power are displayed on a screen that both the participant and examiner can view. This device may not be feasible in large epidemiologic studies due to high participant burden (5-10 total leg presses per leg required). Additionally, those with difficulty or inability getting in and out of a seated position or maintaining the position for testing may be excluded, which may include some of the most frail older adults. Potential for a learning effect exists, which may impact results of both cross-sectional and longitudinal studies utilizing this measure. The Nottingham power does not separate force and velocity components of muscle power, so this method cannot be used to determine if one component is more predictive of outcomes compared to the other in older adults.

Reliability has been assessed for the Nottingham power rig. In a study of N=46 adults 20-86 years (44 ± 23 years) with an older adult group (74 ± 9.1 years) who could walk without an assistive device and able to climb stairs, initial and repeat measures were separated by approximately 1 week.[45] The initial and repeat leg press testing was completed by all subjects, including the older adults 65-83 years. All participants reached their maximum power within nine leg presses (usually within five) though there was evidence of a learning effect. Fatigue during testing was not reported and there were no significant within-subject differences from the two tests (data not shown). The power measures from the initial and repeat measures were significantly correlated (r=0.97; CV=9.4%), indicating high reliability. However, correlations were not age-stratified, so the exact reliability in older adults cannot be determined from this study. The reliability of the Nottingham power rig was examined in N=55 men from the MrOS Study (73 years, 96.3% white) with the maximum power determined from 9 pushes for both the right leg and the left leg.[46] The repeat power testing occurred 1 week after the initial testing. Coefficient of variation (CV) for between-examiner consistency ranged from 2.6% to 3.5%, with the best consistency for maximum power of either leg (compared to maximum power of the right or left leg). The CV for the combination of within-examiner variance, within-participant variance, and machine variance ranged from 10.6% to 10.9%. The CVs for between-participants ranged from. CV estimates did not change with further adjustments for age, BMI, smoking status, number of IADLs, and self-reported health status. Power from the Nottingham power rig has not been compared to multiple other muscle function measures in older adults with a range of function and validity estimates have not been reported.

2.3 Knee Extension

2.3.1 Kinetic Communicator (Kin-Com)

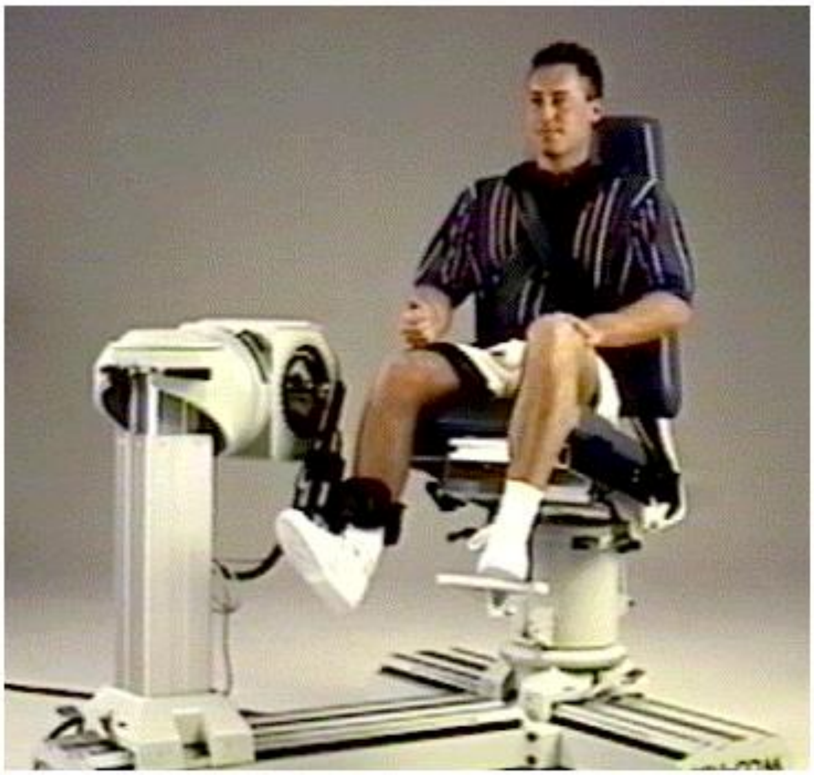

Figure 4. Kin-Com dynamometer

Picture from Health ABC isokinetic quadriceps strength operations manual

Isokinetic dynamometers test muscle performance as the participant applies force. The Kinetic Communicator (Kin-Com, Chattecx Corp., Chattanooga, TN), is an electromechanical device that can measure isokinetic muscle performance of most major joints in the human body[47] with force (Newtons), torque (Newton-meters, Nm), range of movement (degrees), angular velocity (degrees/second) and duration (seconds) as the variables obtained. Objective measures of peak torque, average torque and angle specific torque can be used clinically to represent performance of the muscle group being tested.[47] The KIN/COM has 4 modes of exercise, isokinetic (concentric and eccentric), isometric, isotonic and passive which can be tested through a range of angular velocities between 0 and 210°/s, though studies have found that muscle performance at one speed is highly correlated with performance at other speeds.[48] In Health ABC, Kin-Com was used to assess quadriceps strength at 60°/s. The reliability of the operating systems of KIN/COM was established in young adults,[49] though has not been established in older adult population. One study on older adults tested the reliability of isokinetic testing at the ankle and found that inter-rater reliability was high (r=0.87-0.95) for plantar flexion and dorsiflexion tests where average strength was >10 Newton-meters (Nm), though less reliable (r=0.42-0.75) in weaker adults with average strength <10 Nm.[50] The Kin-Com may only be reliable in older adults with higher levels of function, and level of function should be considered when using the Kin-Com to assess quadriceps strength in studies that include older adults who are very weak or with low functional levels.

2.4 Jump Tests on Force Plate

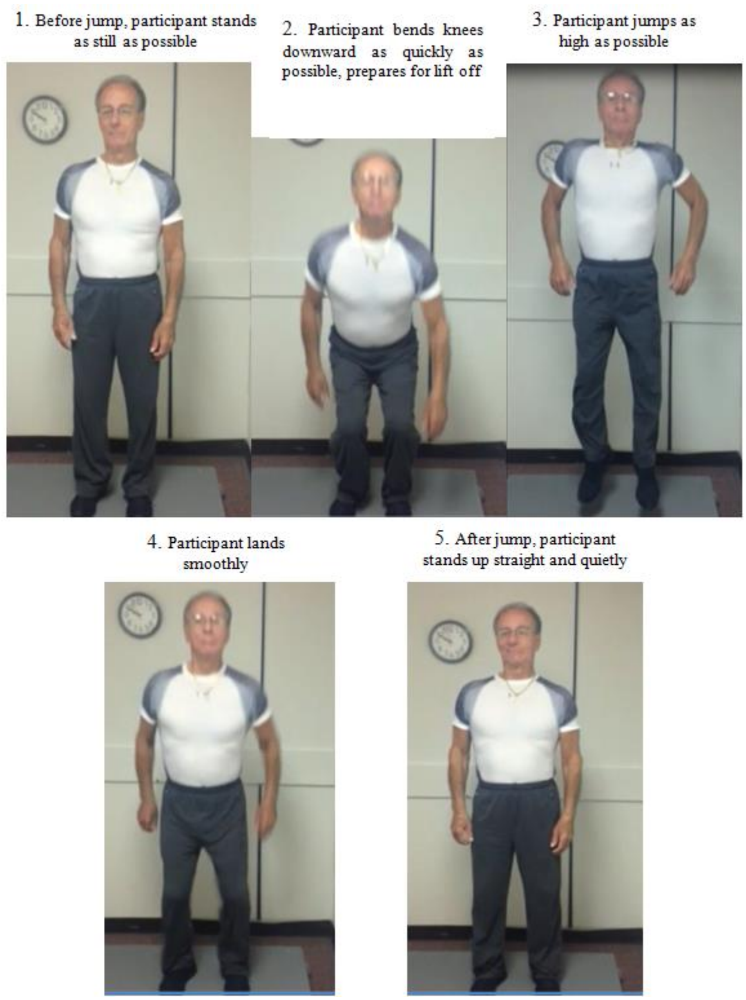

Figure 5. Jump test in MrOS

(Strotmeyer ES et al., JHNA 2018)

Jump tests performed on a force plate have been recently used to measure muscle power in older adults. Different protocols have been used, though participants stand on a force plate and perform a counter movement jump: a rapid downward movement (i.e. bending the knees) immediately followed by a rapid upwards movement (i.e. extending the knees) while trying to jump as high as possible (Figure 3). Muscle power is calculated during the push-off phase, which is independent of the ability to generate an upwards impulse large enough to produce an actual flight phase. Therefore, older adults who are unable to jump may have power measures in addition to those with flight time. The protocol simply requires that the movement is performed at the participant's maximum velocity. Muscle power (Watts), force at peak power (Newton), velocity at peak power (m/s) and jump height can be quantified from the jump test. Muscle power and force can be corrected for body-weight to account for overall body size since heavier people will have greater absolute muscle power (Watts) compared to lighter people. A standard protocol has not been developed for jump testing.

Jump testing on a force plate is a novel approach for measuring muscle function and few studies have examined the feasibility, reliability and validity of this test. In a cross-sectional study of men[51] (older group n=20, age 81.4±7.5 years; younger group n=20, age 27.8±2.4 years) and women (older group n=20, age 74.2±9.0 years; younger group n=20, age 25.9±3.4 years), countermovement jumps were performed on a ground reaction force platform (Leonardo Mechanograph; Novotec Medical, Pforzheim, Germany). Participants were instructed to jump as high as possible and performed 3 single jumps with unlimited rest to fully recover between jumps. Additional jumps were performed, if necessary, until 3 jumps were deemed valid by the software. Invalid jumps occurred when participants did not completely land on the force plate, force changed more than 20 N during the phases before and after the jump because of movement, or the volunteer lost balance after landing and took an extra step. If participants could not completely lift off of the force plate during a jump, power could not be measured. Jumping had no injuries, fractures or self-reported pain, though reliability and/or validity were not discussed. Only 20% of 40 total participants had normal bone mineral density (BMD); 17% had prevalent fractures, 55% had had BMD T-scores in the osteopenic range (DXA T-score -1.1 to -2.4) and

8% had osteoporosis (DXA T-score ≤-2.5). Even those with low BMD or previous vertebral fracture did not report pain, injury or experience a fracture during or after jumping. Jumping was 'safe' in this population, though included a small sample and a limited definition of 'safe' was investigated by this study. Jump testing should be implemented in larger studies of older adults with low and high function in order to determine the safety of this measure.

Jump tests have not been widely used in large epidemiologic studies. However, one study examined the short-term error and learning effects of jumping and other standard tests of locomotor performance. Rittweger et al.[52] studied women (n=22) and men (n=14) aged 60.8±19.0 years completing repeat testing of the Timed Up and Go (TUG), free gait speed, maximum gait speed, chair-rise test and the jump test. Participants were instructed to jump as high as possible on a ground reaction force platform (Leonardo Mechanograph; Novotec Medical, Pforzheim, Germany). Peak power during the acceleration phase (during concentric contraction) was analyzed. The retest was conducted two weeks after the initial test, and at the same time of day as the initial test. The jump test had the lowest short term error (E_{ST}=3.6%), highest correlation coefficient for test-retest values (r=0.99) and the highest coefficient of variation for intersubject variability (CV=45.4%) compared to other measures: Timed Up and Go (E_{ST}=5.28%; r=0.90; CV=25.5%), free gait speed (E_{ST}=4.02%; r=0.93; CV=24.0%), maximum gait speed (E_{ST}=3.69%; r=0.97; CV=30.6%) and chair-rise test (E_{ST}=5.10%; r=0.91; CV=30.9%). No significant learning effects were observed in a subset of 11 men and 11 women. Though the jump test was found to be reproducible in physically competent older adults and more reproducible than other tests that are commonly used in epidemiologic studies of aging, the relationships between muscle function tests and if these results apply to older, more frail adults are unknown. Older adults may perform the jump test with a wide range of strategies such that those with low to high functional abilities are able to perform jumps.

Muscle power obtained from jump testing was shown to be a reproducible measure in older adults. Holsgaard Larsen et al.[53] studied healthy community dwelling older women (n=18) aged 72.3±6.6 years voluntarily participated in multi-component activities once per week. Included participants were those with no history of orthopedic or neurological disorders and no bone fractures in the lower extremities in the past 5 years. Single-joint isokinetic and isometric measurements of muscle strength for quadriceps, hamstrings and plantar flexor muscles and a multi-joint counter movement jump measurement of muscle power were collected at an initial test session and a retest session. The retest session occurred no sooner than 10 days and no later than 21 days after the initial test session. No significant test-retest differences in mean power normalized to body weight (12.26±2.04 watts/kg test vs. 12.26±2.04 watts/kg retest; p=0.65) existed over this period. This study defined CV<5% as excellent and CV 5-10% as good. Reproducibility of power (CV=5.14%) measured by the counter movement jump was excellent to good, while the reproducibility of isokinetic and isometric strength measures for the quadriceps (CV range 7.95 – 9.99%), hamstrings (CV range 7.35 – 18.99%) and plantar flexor muscles (CV range 7.95 – 9.99%) was good to moderate in older women. Better reproducibility was found for the jump vs. isometric strength measures in this population of older women. This study was limited due to a very small sample of Danish women. Reproducibility may be better for the jump test in women compared to other muscle function measures since they are body-weight bearing and do not require pushing against a fixed load. Studies that determine the reproducibility in both older men and women will be necessary in order to show that power measured during jumps can be utilized across studies of older adults.

2.4.1 Chair Rise

The chair rise test is a widely used measure of functional strength, particularly among older adults. The chair rise test is measured by the time required to rise from a chair multiple times from without use of arms. A systematic review of 10 article assessing the intraclass correlation coefficient (ICC) to describe the test-retest reliability.[54] Sample sizes ranged from 21 to 199 and the total sample was 779. The intervals between the initial test and retest ranged from 2 days to 10 weeks, though 1 study involved only test session. Protocols also varied in number of chair stands (5 or 10 repeated stands, or total number of stands in 30 seconds). The ICCs reported in the articles ranged from 0.64 to 0.96 and the adjusted mean ICC calculated from the reported ICCs was 0.81. The test-retest reliability of the chair rise test can be interpreted as good to high in community-dwelling older adults. These studies differed in the samples tested. Six studies involved presumably healthy community-dwelling individuals, whereas 2 focused on patients with back pain and 1 addressed those with osteoarthritis and another tested individuals with moderate to severe disability. The chair stand test may be more feasible in studies of older adults due to shorter test time and less expensive equipment. However, those who cannot rise from a chair will be excluded, resulting in a floor effect. Additionally, stands/second is not a direct measure of muscle function.

2.5 Strength and Limitations

Several muscle function measures have been reproduced and validated in older adults. However, these tests have important limitations. Most cannot be used over a wide range of performance levels and have disadvantages for testing older adults with either high or low functional ability. For example, the chair rise test has a floor effect since those who cannot rise from the chair cannot be tested. In addition, these measures typically examine only one feature of muscle function, such as power only or strength only. The method chosen to measure muscle function may depend highly on the characteristics of the population being studied, such as functional ability or comorbid conditions, and the outcomes being assessed.

3.0 Background of Muscle Function in Aging Populations

Muscle function is measured in several ways in studies of older adults. Muscle power, a measure of contractile force and shortening speed (force x velocity) is defined as the ability of a muscle to exert a given force quickly.[32] Muscle strength is the most often measure used in cross-sectional and observations studies to assess muscle function, though muscle power decline begins before muscle strength decline in older adults.[55,56] Decline of power has implications in the aging population, including potential associations with poor physical function or performance and disability. Older community-dwelling adults free of disability at baseline with the lowest performance scores for standing balance, usual walk speed and repeated chair stands time at baseline were 4 – 5 times more likely to have subsequent disability compared to those with the highest performance scores.[57] Correlations between objective measures of muscle power, strength and physical performance have shown different strengths of association by sex and specific measure. Leg extensor power measured on the Nottingham power rig was correlated with isometric knee extension strength (r=0.72 in men; r=0.71 in women), stair climb (r=0.58 in men; r=0.47 in women) and chair rise (r=0.38 in men; r=0.56 in women).[58] Isometric knee extension strength was correlated with chair rise (r=0.46 in men; r=0.35 in women).[58] Varying muscle power and strength measures may have different relationships to objective physical performance measures, though these relationships are not well characterized. Decline of lower extremity muscle power as a predictor of objective physical performance in older adults has not been well-studied.

3.1 Demographics

3.1.1 Age and Sex

Cross-sectional studies have been conducted in younger and older men and women to assess the association between jump power and age.[51,59,60] Buehring et al.[51] studied men (older group n=20, age 81.4±7.5 years; younger group n=20, age 27.8±2.4 years) and women (older group n=20, age 74.2±9.0 years; younger group n=20, age 25.9±3.4 years) who were able to stand independently. Mean jump power normalized to weight was significantly higher in the younger age group (45.5±9.9 watts/kg) compared to the older age group (20.7±6.5 watts/kg). Jump height was significantly higher in the younger age group (42.3±10.3 cm) compared to the older age group (16.4±6.6 cm). Rantalainen et al.[59] studied young athletic women (n=221, age 23±4.7 years) and early stage osteoarthritic postmenopausal women with no regular physical activity (n=82, age 57.7±4.2 years). Women in the young group had higher jump power (2660±550 watts) compared to women in the postmenopausal group (1870±360 watts). Runge et al.[60] studied men (n=89) and women (n=169) aged 18-88 years in Germany who were free of motor performance limitations as defined by the ability to walk at least 800 meters without an aid, climb a standard staircase without difficulty and perform two-legged and one-legged jumps. Significant negative correlations existed between higher age and lower weight-specific power (watts/kg) for both women (r=-0.81) and men (r=-0.86). All three studies showed that older adults had significantly weaker leg power compared to younger adults. Determining a causal relationship between age and power was not possible in these studies due to their cross-sectional design. Other critical risk factors that may explain the association between power and age were not measured, such as age-related lifestyle changes and chronic disease. Longitudinal studies that include other confounding factors will better elucidate the relationship between power and age.

Sex-specific differences in the determinants of muscle power may exist and determining sex-specific measures of power that are appropriate for older adults is crucial. Caserotti et al.[31] conducted a cross-sectional study of community dwelling men (n=48) and women (n=37) aged 75 years in Denmark who had no regular physical activity. Older men achieved higher peak muscle power normalized to weight than older women (23.0±4.09 watts/kg vs. 18.67±3.27 watts/kg; $p<0.0001$) during the concentric phase of the jump and jumped higher (9.85±3.51 cm vs. 5.93±2.43 cm; $p<0.0001$), primarily attributed to the higher velocity component of the jump. Women had lower maximal jump velocity (1.38±0.17 m/s vs. 1.64±0.21 m/s; $p<0.0001$) and lower take-off velocity (1.06±0.22 m/s vs. 1.36±0.26 m/s; $p<0.0001$) compared to men. Peak power did not differ by sex when normalized to lean body mass. Additionally, no correlations were observed between items from the physical performance test (chair rises, 2.8 meter walk, putting on and removing a jacket, and picking up a coin from the floor) and power. Women had slower velocity, suggesting that women may be more impaired in terms of having the ability to regain balance. Siglinsky et al.[61] assessed sex differences in power and physical function in older (mean age 65.4±17.4 years) men (n=119) and women (n=213). Two jumps were performed on a force plate and the jump with the maximal height was used for analyses of jump height and power normalized to body weight. Grip strength and the Short Physical Performance Battery (SPPB) (tests of balance, gait speed and timed chair rise) were performed. Appendicular lean mass from DXA to jump height ratio (ALM/ht^2), a commonly used measure for sarcopenia staging, was also collected. Men had higher jump height (0.27±0.11 m vs. 0.20±0.07 m), relative jump power (28.5±10.5 W/kg vs. 21.9±7.1 W/kg), grip strength (35.5±9.8 kg vs. 22.7±7.0 kg) and ALM/ht^2 (8.25±1.35 kg/m^2 vs. 6.99±1.38 kg/m^2) compared to women (all $p<0.0001$). No sex differences existed for gait speed, timed chair rise and total SPPB. Age was negatively correlated with both jump height (men R^2=0.57; women R^2=0.38) and power (men R^2=0.61; women R^2=0.44) (all $p<0.0005$). These correlations were higher than the correlations between age and grip strength (men R^2=0.23; women R^2=0.27, ALM/ht^2 (men R^2=0.25; women R^2=0.27), timed chair rise (men R^2=0.27; women R^2=0.28) and gait speed (men R^2=0.05; women R^2=0.03). Age was inversely associated with jump power, though the relationship was stronger is men compared to women. These results show large sex differences in jump test measures (power, height and velocity), but may be due to the differences in lean mass between men and women since no differences were seen after adjustment for lean mass. Muscle power and physical performance have both been used in studies of older adults as measures of overall function. However, these results indicate that power and physical performance measures should not be used interchangeably to measure overall function. Finally, these results are limited in generalizability due to the small Danish sample size and the inclusion of only physically inactive older adults. It will be important to examine sex differences in larger cohorts of older, racially-diverse men and women with varying levels of function.

3.2 Lifestyle Characteristics

3.2.1 Physical Activity and Exercise

Few observational studies have found positive associations between physical activity and muscle strength. In 697 community-dwelling participants (mean age 62±7; 49% women), physical activity (PA) was measured with pedometers and daily number of steps were recorded in a pedometer diary as adjusted for season to reduce seasonality effects on the PA measures.[62] PA was classified as low (42000 steps/day below mean PA), moderate (within 2000 steps of mean PA), or high PA (42000 steps/day above mean PA), though regression analyses used continuous PA levels for associations with muscle function. PA was positively associated with change in leg strength (β=1.37; p=0.001) in women only. Pedometers measure steps only and no information about type, frequency, intensity or duration of activity is provided. Therefore, certain activities that may require more physical fitness than others may result in the same number of steps, such as running compared to walking, will register the same number of steps. Pedometers do not register activities that do not generate steps, such as light household activities, so these common activities in older adults will not register as PA with pedometers. Increases in objectively assessed physical activity may represent a target for improving muscle function in community-dwelling older adults, though improved methods for assessing physical activity objectively in older adults, such as accelerometers, should be studied.

Resistance training (RT), or strength training, increases muscular fitness by increasing both strength (the ability to exert force) and endurance (the ability to continue without fatigue). The American College of Sports Medicine (ACSM) states that increasing or maintaining muscle strength is associated with better cardio-metabolic health, lower mortality risk, fewer cardiovascular disease events, less functional limitations and lower nonfatal disease risk.[63] Training programs that target muscle power and velocity improvements may be more effective at improving physical performance than those that solely incorporate basic resistance training.[64-66]

Exercise intervention trials have incorporated basic resistance training or specialized programs to target power and velocity, though few have examined both types simultaneously. Caserotti et al.[12] studied community dwelling men aged 75 years with no regular physical activity in Denmark (n=39). No changes were found after the 36-week training period in pre-stretch enhancement in counter movement jump compared to squatting jump. The training group participated in sessions for 60 minutes twice a week for 36 weeks that included a 10-minute warm up, aerobics (walking and running), muscle strength exercises using own body weight, endurance, postural control exercises, flexibility and reaction exercises. Those in the intervention group (n=14) jumped higher after training (9.38±3 cm pre-training to 10.82±3.3 cm post-training; $p<0.05$) and had elevated maximal muscle power normalized to weight (22.8 ±3.2 watts/kg pre-training to 24.1±3.7 watts/kg post-training; $P<0.05$) during counter movement jumps. Conversely, those in the control group (n=25) had decreased jump height (10.59±3.6 cm at baseline to 9.9±3.8 cm at 36 weeks; $p<0.05$) and maximal muscle power output (23.8±4.1 watts/kg at baseline to 23.0±4.5 watts/kg at 36 weeks; $p<0.05$) during counter movement jumps. While the results of this study show that training older men may effectively counteract age-related decline in maximal mechanical muscle performance, we do not know why it improves. Women were not studied and results only apply to men. This type of training may not be an option for all older adults who cannot complete these exercises, especially those with functional limitations.

Strength training has been shown to enhance jumping performance. Ramirez-Campillo et al.[67] studied healthy Hispanic women (n=60) defined by self-reported health. All women were free of heart disease, osteoarthritis, severe visual impairment, neurological disease, pulmonary disease requiring oxygen, uncontrolled hypertension, hip fracture or lower extremity joint replacement in the past 6 months. Women who were participating in structured exercise or had participated in strength training in the past 6 months were excluded. Participants were randomized into 3 groups: 12-week high speed strength training (EG; n=20; aged 66.3±3.7 years), 12-week low speed strength training (SG; n=20; aged 68.7±6. yeas), and a control group (CG; n=20; aged 66.7±4.9 years). Training sessions occurred three times per week for 12 weeks and consisted of a 10-minute warm up and stretching, strength training exercises (bench press, standing upper row, biceps curls, leg press, prone leg curl and leg extension), and a cool down with core stabilizing exercises. After the training period, those in the EG and SG had larger increased jump height (cm) than those in CG (23% improvement in EG, 13% in SG and 1% in CG; all $p<0.05$). High speed strength training had a larger impact on jump performance than low speed strength training. Training that includes a speed component, such as power training, may be more appropriate for healthy older adults.

Strength and power training can improve jump performance, and improvements differ by type of training. Correa et al.[68] studied Brazilian women (n=58; aged 67±5 years), excluding those with severe endocrine, metabolic and neuromuscular diseases. Women were first divided into 2 groups: an experimental group that performed traditional resistance exercises for 6 weeks (EG; n=41) and a control group that did not exercise (CG; n=17). After the initial 6-week period, women in EG were divided into 3 groups: traditional group (TG; n=14), power training (PG; n=13) or rapid strength training (RG; n=14) for jump test performance. No difference in jump height (cm) was observed between EG and CG groups after the first 6 weeks. These results were consistent with other studies findings that traditional strength training results in little or no improvement in the performance of jumps,[66,69] but were likely due to the shorter duration of training and use of only jump height, not just power, as the jump variable. After division of EG into TG, PG and RG training groups, performance in counter movement jump was significantly ($p<0.05$) higher in the RG group (25% increase) compared to either the TG (4% increase) or PG (8% increase). Rapid strength training had a larger impact on jump performance than either traditional strength or power training. Healthy older women may benefit most from rapid strength training, though studies including both men and women are necessary for determining the appropriate training programs for all older adults. In both studies[12,67] training focused on muscle function, whether power or strength, was effective in increasing jump height in healthy older women. However, the exclusion criteria of functionally limited older women make these results limited to only healthy women. Examining different types of muscle training in functionally limited older adults will be useful in determining if interventions can improve function in older adults with limitations.

A subjective measure of physical function in healthy older adults has been shown to be correlated with objective measures of strength, power and function. Amesberger et al.[70] studied jump height measured during counter movement jumps in a 12-week skiing intervention group (IG; n=27; aged 67.5±2.8 years) and a control group (CG; n=20; aged 67.3±4.4 years). The Physical Self-Concept (PSK) scale, a self-assessment of motor abilities, including general sportiness, endurance, strength and global physical self, was used to obtain subjective measures of physical function. These were compared to objective measures of strength, including endurance, balance, concentric muscle strength and power from a countermovement jump. All measures were collected at 3 time points: pre-test, post-test and retention test. At all 4 time points, self-perceived PSK strength was significantly correlated with objective strength (r=0.38 in pretest; r=0.44 in post-test; r=0.56 in retention test) and power (r=0.38 in pretest; r=0.44 in post-test; r=0.45 in retention test). This study used both objective and subjective measures of physical health but is limited by the fact that the intervention group consists of high-functioning adults able to downhill ski. These results suggest that asking older adults how they perceive their physical function ability prior to testing, such as jump tests, accurately reflects their objective ability to perform the test.

Jump performance can be improved and maintained through strength training. Pereira et al.[71] studied white women aged 65.5±8.2 years (n=139) with no previous strength training. Jump height (cm) increased in the 12-week training group from pre to post-training, regardless of the angiotensin-converting enzyme I/D (ACE) and alpha-actinin 3 (ACTN3) polymorphisms (reported as influencing variations in skeletal muscle function). Pereira et al.[72] studied white women either in the 12-week training group (EG; n=28; aged 62.5±5.4 years) or the control group (CG; n=28; aged 62.2±4.3 years). Jump height (cm) significantly increased in EG (40% from pre to post-training; $p<0.05$) but not in the CG. Pereira et al.[73] conducted a follow-up study to assess the change in jump height from the end of the 12-week training period to 6-weeks after training ended (DT). Jump height was maintained by those in the EG but decreased in the CG at DT (10% change for CG; $p<0.05$). In all Pereira articles, jump tests were incorporated but only jump height was measured. Jump power, not jump height, has been shown to be a valid measure to assess physical function in older adults. Therefore, the meaningfulness of this outcome is unclear.

Power training in older adults with slow gait speed can increase strength and gait speed. Hvid et al.[74] examined the effects of power training on muscle strength and gait speed in a two-arm randomized control trial. Participants were community-dwelling older men and women (n=37; aged 82±1 years) who were mobility-limited defined by 3-meter gait speed<0.9m/s and cognitively intact (mini-mental state examination (MMSE) >21). Exclusion criteria included amputation or other major physical impairments, terminal and severe diseases (cancer and severe heart failure), ECG abnormalities, surgery or fracture in the past 6 months, uncontrolled hypertension (blood pressure>160/100 mmHg) and severe pain prohibiting exercise. The training group (TG) received 12 weeks of high-load power training two times per week. Training included upper body, balance, and explosive (as rapid as possible) lower body exercises with specific emphasis on leg press and plantar flexion. Participants performed 3 sets of 10 repetitions during weeks 1 through 6 and 3 sets of 8 repetitions during weeks 7 through 12 with loads corresponding to 70–80% of maximum and adjusted progressively. The control group (CG) did not participate in any training. Muscle strength was assessed using a KinCom dynamometer with the interpolated twitch technique to evaluate voluntary muscle activation. Gait speed (m/s) was calculated as distance covered during a 2-minute maximal walking test (2-MWT). No between-group differences were observed in muscle strength or 2-MWT at baseline. Muscle strength significantly increased in TG (98.9±7.7 Nm at baseline to 113.1±7.5 Nm post-intervention) but not CG (101.9±0.1 Nm at baseline to 102.7±8.3 Nm post-intervention). Gait speed significantly increased in TG (1.00±0.06 m/s at baseline to 1.09±0.007 m/s post-intervention) and decreased in CG (1.06±0.04 m/s at baseline to 1.03±0.04 m/s post-intervention). Significant between-group changes in muscle strength (TG vs. CG: +13.4 Nm) and gait speed (TG vs. CG: +0.12 m/s) were observed. High-load power training with emphasis on rapid movements of the lower body can improve both muscle strength and gait speed in those with mobility impairments. Implementing power training in adult populations with impaired mobility may also impact those who are at the greatest risk of falling.

Overall findings of previous exercise training intervention studies were that muscle strength,[74] jump power[12] and jump height[12,67,68,71,72] increased with training and improvements were maintained 6 weeks after training ended.[73] In particular, high-load power training increased gait speed.[74] Power and/or strength training are feasible strategies to maintain or improve muscle function in older adults. However, many poor health outcomes, such as falls, mobility limitations and disability in older adults were not studied in relation to jump power, which is a limitation of the current literature. Additionally, these training studies included men and women who were healthy and functional, which is not representative of the entire older adult population and excludes those older adults with the lowest muscle function. Studies that examine the associations between strength and power interventions and disease outcomes in large populations of adults with comorbid conditions and varying levels of function are crucial.

3.3 Musculoskeletal

3.3.1 BMD and Sarcopenia

Jump power has been related to poor skeletal outcomes. Rantalainen et al.[59] found that jump power was significantly correlated with bone strength indices ($r=0.43$ to 0.54; $p<0.0001$) measured with peripheral quantitative computed tomography (pQCT). Hardcastle et al.[75] conducted a cross-sectional study of white men (n=70) and white women (n=119) aged

57.0±13.7 years from the high bone mass cohort in the U.K. and assessed bone strength with pQCT. Multiple linear regression models for bone outcomes and jump test power were adjusted for age, gender, height and weight. All outcomes and exposures were standardized. The standardized β coefficients represent standard deviation (SD) change in outcome per SD change in the log jump power (kilowatts) exposure. Jump power was strongly associated with higher total hip BMD (β=0.29; p=0.01), midtibial cortical area (β=0.29; p<0.01), cortical BMD (β=0.39; p=0.02), total bone area (β=0.10; p=0.33), cortical to total bone area ratio (β=0.26; p=0.11), and tibial strength strain index (β=0.26; p<0.01) and inversely associated with endocortical circumference (β=-0.24; p<0.01). Self-reported physical function, diabetes, smoking status and alcohol use were collected though not adjusted for in analyses. The relationship between power and skeletal outcomes needs to be assessed further in order to determine if an independent association exists, after accounting for common risk factors associated with aging.

Sarcopenia, the age-related loss of muscle with low muscle strength and/or low muscle performance.[76,77] may also be related to low muscle power. Singh et al.[78] conducted a cross-sectional study of men (n=37) and women (n=33) in the U.S. aged 55-75 years to assess the link between sarcopenia and jump power. All participants performed isotonic muscle strength tests (1-repetition maximum tests for 2 leg presses, right hip abduction and left hip abduction) and a jump test (power, height and airtime). The relative skeletal muscle mass index was calculated (RSMI (kg/m^2) = appendicular skeletal muscle mass/height^2) and used to define sarcopenia based on the Baumgartner et al[3] definition (RSMI<7.26 kg/m^2 in men and RSMI<5.45 kg/m^2 in women). Leg press strength and hip abduction strength were not significantly different between the sarcopenia group and normal group and results were not attenuated when normalized to body weight. Jump height and airtime were not significantly different between groups. However, those in the sarcopenia group (n=12) had significantly lower jump power normalized to body weight vs. those in the normal group (n=48) (9.95±0.32 W/kg vs. 11.16±0.26 W/kg; p=0.031). Jump power may be a better indicator of muscle performance in older individuals than isotonic muscle strength testing techniques that typically use external strength. These results may be applicable to frail older adults, though the definition of sarcopenia is not detailed or supported by previous literature. However, the sample size was small, n=60 total people and only n=12 had sarcopenia. Longitudinal assessments are important to determine if jump test measures predict future sarcopenia.

Jump height and power has been associated with sarcopenia, physical function and other muscle parameters in older adults. Siglinsky et al.[61] also studied these relationships in older adults. Grip strength, SPPB components of balance, gait speed, timed chair rise were measured and appendicular lean mass from DXA to height ratio (ALM/ht^2) were collected. These measures were used to define sarcopenia based on 3 definition: (1) The Foundation of the NIH (FNIH) definition (ALM/BMI <0.789 for men, <0.512 for women; grip strength <26 kg for men, <16 kg for women)[7]; (2) The European working group definition (ALM/ht^2 <7.26 kg/m^2 for men, <5.45 kg/m^2 for women; grip strength <30 kg for men, <20 kg for women; gait speed ≤0.8)[5]; (3) The international working group definition (ALM/ht^2 ≤7.23 kg/m^2 for men, ≤5.67 kg/m^2 for women; gait speed <1.0 m/s)[6]. Jump height and power were weakly correlated with ALM/ht^2 (height and power R^2=0.14), total SPPB (height and power R^2=0.27) and gait speed (height and power R^2=0.10). Jump height and power were moderately correlated with grip strength (height and power R^2=0.32) and timed chair rise (height R^2=0.30; power R^2=0.33). Regression analysis showed that jump power was independently associated with age, BMI, ALM, jump velocity, jump force and timed chair rise. Finally, sarcopenic adults had significantly lower power compared to non-sarcopenic adults (16.1%, 23.5% and 31.5% difference between groups) regardless of which of the three definitions was used for sarcopenia classification.

3.4 Aging Diseases

Chronic conditions that are associated with impairments of lower-extremity functioning and mobility may be related to muscle function in older adults. A review of 16 total studies of leg muscle power and osteoarthritis, diabetes and cardiovascular disease among older adults.[79] In studies of osteoporosis (n=5, mean age range: 61 to 72 years), leg muscle power was measured by Nottingham, Keiser or dynamometer was associated with osteoarthritis. In studies of diabetes (n=5, mean age range 58 to 74 years), leg muscle power measured by Nottingham or dynamometer was associated with diabetes. In studies of cardiovascular diseases (N=6 of chronic heart failure, cardiovascular disease; or peripheral vascular disease; 60 to 80 years), leg muscle power measured by Nottingham or dynamometer was associated with cardiovascular diseases. Because there is a lack of standardized leg power measure, there was heterogeneity among studies in what method was used to assess leg power. Additionally, the chronic diseases were largely from self-report. Including objective measures of chronic diseases, such as those that include physician diagnosis and laboratory testing for diabetes, will improve the risk estimates for the relationships between muscle function and these conditions.

4.0 Methods for Fall/Fall Injury Assessment in Older Adults

Preventing falls and fall injuries in targeted, at-risk populations of older adults is a large public health concern. However, fall and fall injury definitions and the methods for identifying these events, including timing, frequency, length of follow-up and mode of assessment, vary across studies of risk factors for falls and fall injuries. Falls data can be collected in several ways, including retrospective self-report (telephone interview, face-to-face interview, or mailed questionnaires), prospective self-report (postcards, calendars, or diaries), and/or abstraction from medical records or claims data.[80,81] Although fractures have been collected often with Medicare claims data (e.g., Medicare fee-for-service data), this method has generally not been used to assess falls and all fall injuries, including non-fracture injuries. Taylor et al[82] and Ray et al[83] used algorithms to identify fracture events in claims data. Although this method was not standardized or validated, primary and secondary International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9) diagnosis and procedure codes from acute inpatient, skilled nursing facility and emergency department files, as well as external cause of injury codes (E codes) were used to identify fall-related events. Tinetti et al.[84] classified fall-related events from ICD-9 codes as: hip fractures, other fractures, head injuries, joint dislocations or accidental falls. Kim et al.[85] modified the algorithms used to extract fractures in order extract other fall-related injuries, including both fractures and non-fracture evens, from Medicare claims. Importantly, not all injuries have been included in the algorithms used, such as sprains, strains or contusions. Specific algorithms must be validated to capture all treated fall injuries in Medicare claims.

Currently, only some studies using claims data include non-fracture fall injuries. The lack of a standard measure of falls and fall injuries across studies significantly impedes comparison of the risk estimates across studies since an algorithm that includes more injury types may result in a higher estimate compared to an algorithm that includes less injury types. Additionally, without adjustment for risk factors, including demographics, lifestyle characteristics, comorbid conditions and medication use are confounding factors, fall and fall injury risks may be overestimated. Subsequently, the development of fall prevention strategies may be impacted by inconsistent risk estimates and the at-risk populations that may be identified with use of different algorithms for identifying fall-related events. Evaluation of the methods for fall and fall injury data collection is necessary in reviewing studies of these events in older adult populations. Specifically, the definitions of falls and fall-related events, timing, frequency, length of follow-up and mode of assessment must be considered.

4.1 Self-Report Questionnaires

Self-report of falls and fall injuries is a common method for collecting data about fall events in older adults. In a systematic review of cohort studies that examined the effect of different self-reported falls collection methods in community-dwelling older adults, the methodology for fall data collection varied across the 6 studies in the review, including fall definitions, timing, frequency, length of follow-up and mode of assessment.[86] All studies defined a fall differently: (1) falling all the way to the floor or ground, or falling and hitting an object like a chair or stair; (2) an unintentional event where the older person came to be on the floor without the feet weight-bearing; (3) inadvertently coming to rest on the floor or another lower surface but was not due to syncope, seizure, stroke, or an overwhelming displacing force; (4) touching the ground or some lower level unintentionally with the hand, elbow or buttock, including falling down from a ladder, stool or bicycle; (5) fall occurring through the loss of balance causing the person to hit the ground or other object at lower level; (6) touching the ground or floor unintentionally with a body part other than the soles of the feet. The multiple fall definitions, including differences in wording, language and clarity of the questions may affect the response such that a person who reports not having a fall may have reported a fall if the question had been worded differently, and therefore limits the comparisons of results across studies. Because a standard definition for a fall or a fall-related injury does not exist, the definition should be considered when evaluating studies of these events in older adult populations.

Fall data has been collected both retrospectively and prospectively, though a standard method does not exist. Retrospective methods were compared to prospective methods for fall data collection with the prospective method considered the "gold standard" method in each study. However, both the retrospective methods and the "gold standard" prospective methods varied according to timing, frequency, length of follow-up and mode of assessment for data collection across studies. The "gold standard" prospective methods included: (1) weekly postcards mailed in by participants with a telephone call for those not mailed back and a home visit within 3 weeks to collect additional information about the fall; (2) asked weekly if they had fallen with additional monthly diaries, (3) weekly postcards mailed in by participants with a telephone call for those not mailed back or if a fall was reported; (4) in-person interviews every 3 months over 1 year; (5) daily fall calendars returned monthly with telephone calls for those not mailed back or if a fall was reported; (6) monthly postcards sent to participants asking about falls in the past 2 months. The retrospective methods included: (1) telephone interview at the end of 1 year asking about falls in the past 12 months; (2) questionnaire every 3 months (though in a different population than those used for the "standard" prospective measure); (3) final postcard at the end of 1 year asking about falls in the past 3, 6 and 12 months; (4) final in-person interview asking about falls in the past 12 months; (5) final questionnaire asking about falls in the past 12 months; (6) final postcard at the end of 1 year asking about falls in the past 3 and 12 months (using 2 separate populations from the population used for the criterion measure). Comparing retrospective methods to "standard" prospective methods that all vary methodologically in terms of timing, frequency, length of follow-up and mode of assessment may impact the ability to compare results across studies. Studies

Even though major methodological differences exist across studies, sensitivity and specificity estimates were provided for self-reported fall injury methods. The major findings from this review were that the retrospective methods of a fall in the past year were specific (91-95%) but less sensitive (80-89%) compared to the prospective methods. Results varied and depended on the frequencies and time frames of recall, which is likely due to tremendous variation in the timing/frequency (daily, weekly, monthly, at 3 months, at 6 months and/or at 12 months) and mode of assessment (postcards, diaries, fall calendars, phone calls, questionnaires and/or in-person interviews) for collection of fall data across these studies. For example, the sensitivity of recall for ≥1 fall was 74% for 6-month recall of falls and 68% for 3-month recall of falls. Additionally, in one study those with poor cognitive function were less likely to recall a fall in the past 12 months. More frequent fall assessments, such as in the past 3 or 6 months or using prospective methods, may be better in populations with cognitive impairments. However, studies generally do not consider the impact of cognitive function on recall of falls and fall-related injuries and may underestimate fall risk in those with lower cognition if relying on longer time frames, such as 12 months, for recall of falls. Prospective methods are less likely to result in recall bias and have similar specificity, though higher sensitivity, compared to retrospective methods and it is likely that prospective methods are better for collecting fall and fall injury data in older adults.

No studies have directly compared retrospective to prospective self-report methods for all fall injuries in older adults, though the same limitations from studies assessing falls apply to assessments of fall injury, including varying definitions, timing, frequency, length of follow-up and mode of assessment for data collection. Definitions of fall injury may include fracture, head injury, sprain/strain, bruise, bleeding, or other injury type from a fall. However, studies have used different definitions which include some but not all injuries. The sensitivity and specificity of recall for fall injury may be better compared to prospective methods in older adults if a more serious event, like a sprain/strain or a fracture, occurred and may be recalled with higher accuracy than fall with no resulting injury, especially if the injury required medical attention.

Many, but not all older adults who experience a fall or fall injury discuss the event with a healthcare provider, though not all who discuss the event receive fall prevention strategies. The Medicare Beneficiary Survey (MCBS) falls supplement includes community-dwelling Medicare beneficiaries ≥65 years old and asks “In the past year, how many times have you fallen down?” and subsequently the following questions: how many times have you fallen down?, “did you hurt yourself badly enough to get medical help?”, “did you talk to a doctor or other medical professional about that fall/any of those falls?”, “did the healthcare provider talk with you to understand why you fell?” and “did the healthcare provider talk with you about how to prevent future falls?"[87] In the 2002 MCBS,[88] 22% reported a fall in the previous year with 10% reporting recurrent falls. Compared to those who reported a fall injury but did not seek medical attention, those who sought medical attention (33%) were older and more likely to be women, living alone, not married, report poor or fair health and have difficulties with activities of daily living and instrumental activities of daily living. Additionally, 48% reported talking to a healthcare provider about the fall, 75% reported that the healthcare provider attempted to understand the circumstances of the fall and 61% reported receiving fall prevention information. The prevention information was based on the American Geriatrics Society's guidelines for the prevention of falls in older persons that includes multifactorial interventions of gait, balance and exercise programs, medication modification, postural hypotension treatment, environmental hazard modification and cardiovascular disorder treatment.[89] In the 2005 MCBS[90], 36% of men and 50% of women who self-reported falling in the past year discussed falling with their health care provider. Of those who discussed falling with a health care provider, 28% of men and 38% of women reported that the provider tried to understand why they fell. Additionally, of those who discussed falling with a health care provider, American Geriatrics Society's guidelines for fall prevention were discussed with 34% of men and 31% of women. Regardless of the fall outcome or type of injury, 30-50% of older adults reported falls to their health care provider and women were more likely to report the events, indicating that many older adults are concerned about falling, though not all that report falls receive prevention strategies in order to reduce their fall risk. However, as these data are from self-report, future studies should compare self-report of seeking medical attention for falls and fall injuries to medical records or CMS data to confirm that they received medical treatment. These approaches may be less susceptible to recall bias, though they may also be limited in that falls and fall injuries are not always well documented in the medical records or

Medicare claims data. Therefore, multimodal approaches for defining fall injury outcomes may be a better approach.

Self-reported fractures and fall injuries resulting in a hospital visit can be adjudicated with medical records. Gill et al. defined a serious fall injury as a fall (an unexpected event in which the participant came to rest on the ground, floor, or lower level) resulting in a clinical, non-vertebral fracture or that led to hospital admission for an injury and were assessed every 6 months through 3 questions: did a doctor tell you that you fractured or broke a bone?; did you break a bone as a result of a fall?; other than the conditions we just asked you about, were you admitted to a hospital overnight for any other reasons? Two experts blinded to group randomization reviewed the self-reported fall injuries and adjudicated independently relevant medical records, including those from all hospital admissions. Cases were discussed if the reviewers disagreed, and if they still disagreed after the discussion, the information was forwarded to the adjudication committee, which arrived at consensus. A definite fall-related fracture required the fulfillment of 4 criteria: (1) radiologic evidence of a non-vertebral, non-stress fractures; (2) report of a fall within one week of injury; (3) absence of major trauma or periprosthetic fracture; (4) no evidence of pathologic fracture. The non-fracture serious fall injuries required hospital admission and one of the following: (1) non-fracture head injury with loss of consciousness, bleeding by neuroimaging, major facial trauma, or other comparable sequela; (2) consequences of a long lie, such as rhabdomyolysis, dehydration or volume depletion, or hypothermia; or (3) other fall injury, such as a severe sprain. Fall-related events that were likely clinically important but did not meet the operational definition of a serious fall injury were ascertained and defined as an answer of ‘yes’ to the questions ‘have you fallen?’ and ‘did this fall result in an inability to leave home for at least one week?’. The fall injury definition was limited to fractures and other serious fall injuries leading to hospital admission, likely because less severe injuries, such as bruises, cuts, or abrasions, are more difficult to adjudicate since not all result in hospitalization or may be poorly documented in medical records. Utilizing a combination of data sources to adjudicate self-reported falls and fall injuries, such as records from both inpatient and outpatient clinics in Medicare claims, may be more comprehensive for all fall injuries.

4.2 Medical Records/Electronic Health Records

Extracting fall and fall injury events from hard-copy medical records or electronic medical records is an alternative method and eliminates the potential recall bias that occurs when using self-report data collection for falls and fall injuries in older adults. Electronic medical records may be more feasible in large studies of older since they can be standardized, are cheaper once they are set up, have better accessibility for studies with large numbers of participants and are potentially more readable. If hospitals do not have electronic health record systems in place already, use of the hard-copy medical records are better option if setting up an electronic system for study purposes may take too many study resources. The hard-copy medical records may have poor readability or time-consuming. In a study using postcards at the end of 1 year that asked about falls in the past 3, 6 and 12 months, a fall was defined as inadvertently coming to rest on the floor or another lower surface but was not due to syncope, seizure, stroke, or an overwhelming displacing force, only 18% of self-reported falls were documented by the participant's physician in the medical chart.[91] Not all self-reported falls were in the medical records, however we do not know based on the question asked if participants actually reported the fall to their physician, which could account for the missing falls data in the medical records. Additionally, only falls that resulted in serious injuries, such as fractures, may have been reported and non-fracture fall injuries are likely missing from the medical records. Therefore, medical records are not feasible in studies of non-fracture fall injuries that do not show up in medical records.

Self-reported falls and fall injuries, events reported in case notes and events reported to a hospital reporting system were compared. A 14-month prospective observational study nested within a randomized controlled trial of adults (mean age 75±11 years; 53% women) compared three different approaches for assessing falls and fall injuries.[92] Falls were defined as any event when a participant unexpectedly came to rest on the ground, floor or another lower level. Fall injuries were defined as mild (bruise, pain), moderate (loss of consciousness after the fall, dislocation, laceration, sutures) or severe (fracture). Methods compared were (1) participant self-report to the research assistant, (2) report by research assistant to case notes and (3) report by research assistant to the hospital reporting system, with the sum of all three approaches considered the "gold standard". The research assistants were staff on the hospital floors who received training through a single, 10-minute DVD video. The video gave the definition of a fall both visually and verbally, described how falls should be reported in the case notes and hospital incident reporting system, and subsequently demonstrated falls using case simulations. Research assistants were responsible for reporting any fall events (self-reported or witnessed) in the case notes and to the hospital reporting system. A different research assistant reviewed the case notes and participants with falls reported in case notes were also asked about the falls. For falls recorded in case notes, at least two research staff would independently review the data and make conclusions about the nature of the fall, and any disagreements were referred to the site investigators or chief investigator for final clarification/decision regarding the fall data. The hospital reporting system, which had strict control for data access with deidentified reports, was scanned at the end of the study for any fall involving study participants by searching for their unique participant identification number. The list of incident falls from the hospital reporting system was used in two ways: (1) to confirm falls from either self-report or case notes and (2) identify falls that occurred but were not self-reported to research assistant or recorded in the case notes. The hospital reporting system was based off of the Australian Patient Safety Foundation's system,[93] however a description of this method was not provided and it is unclear who reported the falls to the system, when the falls were reported in relation to the incident and if other details (circumstance or severity of the fall) were reported. Variations may exist based on the person reporting fall events and may impact estimates of falls.

Report of fall events varied according to the method for collection. Compared to the "gold standard", 92% of fall events were reported in the case notes, 76% of fall events were reported through the hospital reporting systems, and 60% of fall events were self-reported by participants. Falls that resulted in moderate or severe injury were 2.28 (95% CI: 1.07–4.81) times more likely to be reported in the hospital reporting system than in the case notes or self-report alone. In addition, time of day affected reporting of falls though hospital reporting system. Falls that occurred from 6am-10am were 0.54 (95% CI: 0.29–0.99) times as likely to be reported in the hospital reporting system compared to the case notes or self-report alone, and falls that occurred from 2pm-6pm were 2.86 (95% CI: 1.05–7.76) times more likely to be reported in the hospital reporting system compared to the case notes or self-report alone. The differences based on time of day indicate that missing data from this method are likely not missing completely at random. Therefore, the estimates may be biased and due to systematic differences in who reports falls. Overall, these results indicate that the hospital reporting system may be better for collecting data about falls and fall injuries. The hospital reporting system may also be better for collection of severe fall injury data (i.e., fractures) compared to data for the mild/moderate fall injuries. A major issue with using self-report is that all falls and fall injuries may not be reported to physicians. In addition, among those that are reported, all falls and fall injuries may not be documented by the physicians in the participant medical records or case notes, especially non-fracture fall injuries that may be viewed as less serious events by hospital staff.

In a systematic review of 41 articles examining fall injuries in randomized control trials,[81] the proportion of fall injury events to all falls for each study was calculated and compared across studies. A considerable range in the proportion of fall injuries (3.6%-63.5%) was observed among adults ≥ 65 years and appeared to be related to the type of definition used since the lowest proportions were when fall injuries were defined as fractures only (0.4%-11.3%), higher proportions were with multi-level definitions (23.4%-56.2%) and the highest proportion was for a single definition that included a range of symptoms (e.g. back pain, bruises, strains, cuts and abrasions, and fractures) (63.5%). Variation was high for the proportion of total fall injuries reported across studies (CV=50.1%) and between studies that used subcategories of fall injuries that were fractures (CV=51.5%), serious (CV=68.0%) and moderate (CV=35.4%), though the variation was related to the standardization of definition and outcomes. Additionally, some of this variability may have been due to differences in populations across studies included in the review, though population characteristics are not described and the extent that any differences may have affected the variability cannot be determined. The substantial variations in definitions and methods for measuring fall injuries results in limited ability to compare study results. Most studies that incorporated medical records for assessing fall injuries were for fractures since a radiographic report can usually be obtained for these events; few studies included non-fracture fall injuries in the definition and it is unclear if using medical records to collect non-fracture fall injury data is a valid and reliable method for these non-fracture events. The differences in proportion of reported injuries based on type of fall injury, with the highest proportion for a definition including a range of symptoms, e.g. back pain, bruises, strains, cuts and abrasions, and fractures, indicated that many injury types are missed in collecting fall injury data with definitions that do not include these non-fracture fall injuries.

4.3 Claims Data

Fall and fall injury events can be extracted from Medicare claims data. Medicare is a government health insurance program that primarily covers adults aged ≥ 65 years, though also covers those < 65 years with certain disabilities and people of all ages with end-stage renal disease. The Centers for Medicare and Medicaid Services (CMS) implemented a payment policy that denies incremental payment to hospitals for care that is associated with hospital acquired conditions (HACs)[94] and the most targeted HAC for this policy is falls that occur in inpatient settings due to the high costs associated with this common event. Though ICD-9 codes from CMS have been used to identify falls and fall injuries in hospitals, they have not been used widely in studies of older adults who are not in inpatient hospital settings. Taylor et al.[82] and Ray et al.[83] have used algorithms of ICD-9 and E codes to identify fracture events in claims data, and Tinetti et al.[84] and Kim et al.[85] have used modified versions of these algorithms to extract other fall-related injuries, including both fractures and non-fracture evens, from Medicare claims. However, the methods and claims algorithms used to extract fall and fall injuries from claims data have not been standardized, validated or well-studied in relation to use of self-report or medical records to collect data on falls and fall injuries.

Medicare claims were used to identify fall injuries in hospitalized patients. Falls and fall injuries from ICD-9 discharge codes were compared to falls and fall injuries identified by a fall evaluator or hospital reporting system in Medicare patients from 16 medical-surgical nursing units of the Methodist Healthcare-University Hospital (MH-UH), an urban, major teaching hospital in Memphis, TN.[95] Fall evaluators were utilized for the first 9 months of the study (01/01/07-9/30/07) and included nurse managers, nurse supervisors and study personnel. The fall evaluators provided "around-the-clock" falls assessment of any event reported as a possible fall using standardized data collection and a falls database. The hospital's incident reporting system was utilized for the remaining years of the study (9/30/07-12/312011). Risk managers who were notified of a fall event had one week to conduct a medical record review, ascertain details and resulting injuries, complete the report and close the event file. Files could be updated if there was subsequent notification (for example, from the clinical director of a hospital floor) of additional information regarding the event. All 80,312 Medicare and Medicaid patients from January 1, 2007 through December 31, 2011 were included in analyses, though participant characteristics, including age, race, sex, lifestyle characteristics and medications were not provided. A fall was defined as a sudden, unintentional change in position coming to rest on the ground or other lower level or if a patient was found on the floor by hospital staff. Fall injuries were identified by the fall-specific E codes and discharge ICD-9 codes that CMS determined may affect reimbursement (fracture, dislocation, intracranial injury, crushing injury, burn and electric shock) in combination with a present-on-admission (POA) indicator. Only severe injuries from a fall were assessed using Medicare claims and less serious fall injury types are missing from these definitions.

All fall injuries that were reported were not identified with Medicare claims. Most inpatient falls resulted in harm with only 10% resulting in more serious injuries (initial or prolonged hospitalization, permanent patient harm, intervention necessary to sustain life, or death). However, only 43% of these more serious fall injuries identified by the fall evaluator/hospital reporting system were identified using the ICD-9 codes combined with POA indicators. Very few (no number/percent reported) minor injuries, defined as falls that required intervention but resulted in harm to the patient, were identified using ICD-9 codes. The ICD-9 codes used in this study to identify fall-related injuries do not always detect the most serious fall injuries and rarely detect less serious fall injuries. Though these injury codes were targeted by CMS due to the likelihood of HACs, the incomplete detection of fall injuries with claims data may be due to utilization of a non-inclusive list of fall injury codes for this specific fall injury definition. Additionally, because this study investigated falls in the hospital setting, they suggested that poor identification of less serious fall injuries using ICD-9 codes is desirable because these events may not be clinically important. However, these less serious fall injuries are relevant in the general population of older adults and establishing use of claims data as a valid and reliable method to identify fall injury events is necessary in order to use this method in a more general population of older adults.

Various combinations of the codes used to define a fall-related injury in CMS claims have been used, though the definition and specific algorithm used may impact fall injury prevalence rates. Three different methods for defining a fall injury based on codes in Medicare claims data was examined in relation to medical expenditures in community-dwelling adults ≥ 65 years old from the Health and Retirement Survey[96] by linking this cohort to Medicare claims from 2007-2008 that included beneficiary summary files as well as carrier denominator, inpatient, outpatient, durable medical equipment (DME), home health agency (HHA), skilled nursing facility (SNF), hospice and MedPar standard analytic files. Definition 1 included only the E codes. Definition 2 combined the E codes with a broad set of primary ICD-9 inpatient diagnosis codes for fractures, dislocations, sprains, strains, head injuries and contusions. Definition 3 combined ICD-9 inpatient primary diagnosis codes for hip fractures, other nonvertebral fractures, head trauma, joint dislocations, and injuries identified by E codes with outpatient Current Procedural Terminology (CPT) codes for imaging and repair procedures as fall injuries. Each of the 3 definitions used E codes from inpatient, outpatient, and SNF claims data and definitions 2 and 3 additionally used ICD-9 codes from the carrier denominator files. Participant characteristics, including age, did not differ between definitions, though the method used had important implications for both prevalence of fall injury and annual fall-related injury medical expenditures. Prevalence of fall injury was 1% using definition 1, 13% using definition 2 and 4% using definition 3. Total Medicare costs associated with fall injuries were also compared across the three fall injury definitions. Total Medicare expenditures were $4 billion (95% CI: $2-7) for definition 1, $25 billion (95% CI: $17-33) for definition 2 and $13 billion (95% CI: $9-18) for definition 3. However, these numbers were impacted by the different fall injury prevalence rates for each definition and were not adjusted per fall event to account for these differences. Clearly, the use of Medicare claims data has not well-studied outside of hospital settings and a standardized algorithm for extracting falls and fall-related events has not been developed. Due to having the highest prevalence for fall injury, the algorithm that includes E codes and a more comprehensive set of primary ICD-9 inpatient diagnosis codes (fractures, dislocations, sprains, strains, head injuries and contusions) is better for identifying non-fracture fall injuries in addition to fractures compared to more limited algorithms. These comprehensive algorithms should be considered in studies examining non-fracture fall injuries in older adults.

4.4 Strengths and Limitations

No standard method for collecting fall and fall injury data exists so determining which method to implement in studies of older adults may be difficult. The strengths and limitations of each method must be considered when selecting the appropriate method for a specific population. Self-report questionnaires are an inexpensive and relatively quick method for collecting data on fall injuries and may be ideal for studies with very limited resources. However, no standard self-reported method exists for collecting fall and fall injury data and different definitions, including the language used on questionnaires and the frequency that participants are asked about falls and fall injuries (e.g., every 3 months, 6 months or yearly). Additionally, results may be biased due to differences in recall, e.g. between men and women or those with lower cognitive function.

Medical records may be more objective methods for identifying fall and fall injury events, though only under the assumption that these events are always accurately recorded or reported. Use of medical records may be more time-consuming and costly since medical records must be thoroughly examined to identify events. This is especially true for individuals with extensive medical records and depends on how study investigators decide to use the medical records. For example, using medical records to confirm self-reported fall events will be less time-consuming compared to searching medical records for fall events for all participants in the study. However, it is likely that not all events will be self-reported, and some will be missed if the medical records are used for verification purposes only.

Medicare claims may also be a more objective method for assessing falls and fall injuries, though also only under the assumption that these events are always accurately submitted to Medicare claims. The few studies that have used Medicare claims data use varying codes to classify fall-related events, so comparing prevalence and incidence results, as well as medical cost of medical expenditures for injuries across studies, is limited in that the same injuries are not included in all studies. Use of a standardized algorithm to identify falls and fall injuries in Medicare claims may expedite this process, though this has yet to be developed.

Overall, studies that compared methods for fall and fall injury data collection did not use the same length of follow-up for each method, though follow-up times were not considered in these studies. Length of follow up is especially critical methodologically in studies assessing multiple fall injury types since shorter follow-up may not allow for enough events to accumulate for adequate statistical power for comparisons. Severity of the event may also determine if it is self-reported, documented in medical records, or included in Medicare claims. The method used to identify fall-related events should take into consideration the event types to be studied.

No studies have compared the different assessment strategies to each other for a given time period and an optimal fall and fall injury measure has not been defined. Likely, an ideal method for accurately assessing falls and fall injuries in older adults does not exist and multimodal approaches for collecting falls data may be preferable to relying on a single source alone. However, the agreement and disagreement for identifying fall events between these methods has not been well-studied. Standardizing the methodology for assessing falls and fall injuries would be a next step for studying these health outcomes.

5.0 Fall and Fall Injury Risk Factors in Aging Populations

Falls are the leading cause of both fatal and nonfatal injuries in older adults[18] and these fall injuries are associated with high health care costs and utilization.[29,30] Understanding the risk factors for these poor health outcomes may help clinicians identify those who are at the highest risk for falls and fall injuries and provide interventions to prevent these events. Many studies have examined various risk factors in relation to falls and fall injuries, including demographics, lifestyle characteristics, fall history, subclinical measures, aging diseases and medication use. Tables 1 through 10 include selected risk factors that have been studied in relation to falls and fall injury.

5.1 Lifestyle Characteristics

5.1.1 Alcohol Use

Aging can lower the body's tolerance for alcohol and a variety of problems can result from alcohol intake, including falls and fall injuries, especially in older adults taking certain medications (i.e., aspirin and pain medications) or with health conditions (i.e., diabetes and high blood pressure). Older adults are generally more sensitive to alcohol compared to when they were younger, potentially leading to higher risks for falls and fall injuries that may result from drinking alcohol. Alcohol use is common in older adults, as approximately 40% of adults ≥65 years old consume alcohol (2008 National Institute on Alcohol Abuse and Alcoholism national survey), though methods to measure alcohol intake have been inconsistent in studies of falls and fall injuries in older adults.

Alcohol intake was examined in relation to falls and fractures in older adults (Table 1). In the MrOS study and men were defined as non-users, light users or moderate/heavy users, and also as having a history of heavy drinking or a drinking problem.[97] Light users were at a lower fall risk compared to non-users (RR=0.8; 95% CI: 0.7-0.9), though moderate/heavy users had similar fall risk compared to non-users. Fall risk was also higher in men with a self-reported history of heavy drinking (RR=1.4; 95% CI: 1.2-1.8) or a drinking problem (RR=1.6; 95% CI: 1.3-1.9). The Cardiovascular Health Study (CHS)[98] found lower odds of frequent falls for those who drank 1-7 drinks/week vs. nonusers (OR=0.53; 95% CI: 0.29–0.97) and a higher odds of incident fall risk for those who drank 14+ drinks/week vs. nonuse (OR=1.25; 95% CI: 1.03–1.52). Both studies found that ‘light’ alcohol use was associated with decreased risk of falls. However, the non-user groups could include sicker older adults who do not drink due to poor health and being sick is confounding the association. Additionally, the classification of alcohol intake/use (3-level, 7-level variable) may also impact the results. For example, combining moderate users with heavy users for the 3-level alcohol intake classification may have accounted for the insignificant estimate for this group in MrOS. Older adults may not accurately recall alcohol intake patterns. The risk estimates may only be for those with previous or current severe alcoholism or chronic heavy drinking since older adults may only remember alcohol use that is extremely frequent.

Table 1. Alcohol use and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome; method to measure fall/fall injury; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – alcohol intake	Findings/results
Cawthon et al. 2006[97]	5,689 MrOS	74±6 0% women U.S.	≥2 falls Fractures Post-card every 4 months 3.65 years	Ability to walk unassisted		3-level intake: Nonuse Light (≥12 drinks/y or. <13 drinks/wk) Moderate/heavy (≥14 drinks/wk) History of heavy drinking: ≥5 drinks almost every day History of drinking problem: ≥ 12 drinks ever & ≥2 of 4 on CAGE	↑ risk of ≥2 falls with: Light vs. nonuse (RR=0.8; 95% CI: 0.7-0.9) History of heavy drinking (RR=1.4; 95% CI: 1.2-1.8) History of drinking problem (RR=1.6; 95% CI: 1.3-1.9) NS for fractures
Mukamal at al. 2004[98]	5,841 (cross-sectional) 5,473 (prospective) CHS	73 58% women U.S.	Frequent falls (cross-sectional) Incident fall (prospective) Self-reported in past year 4 years			Nonuse Former <1 drinks/week 1-7 drinks/week 7-14 drinks/week 14+. drinks/week	↓ odds of frequent falls only for 1-7 drinks/week vs. nonuse (OR=0.53; 95% CI: 0.29–0.97) ↑ odds of incident fall only for 14+ drinks/week vs. nonuse (OR=1.25; 95% CI: 1.03–1.52)

5.1.2 Physical Activity

Physical activity (PA), any body movement produced by skeletal muscles that requires energy expenditure, promotes health and prevents chronic disease in older adults.[99] Both low and high levels of physical activity may be associated with higher fall risk (Table 2)[100-105] and this relationship may depend on function. In a 4-year prospective study of community-dwelling women, the two highest PA quartiles (recreational activity, blocks walked, and stair climbing) had higher fall risk compared to the lowest PA quartile (Q3 RR=1.12, 95% CI: 1.01-1.25; Q4 RR=1.26, 95% CI: 1.10-1.44).[103] Women with higher PA levels and ≥1 IADL impairment had an increased fall risk compared to women with lower PA levels (RR=1.31; 95% CI: 1.14-1.52). However, PA level in women with no IADL impairment was not associated with fall risk, indicating that PA may be unsafe for women with functional impairments. The effect of PA on fall risk depended on functional status and recommendations for PA in older adults may need to different for those with and without functional impairments.

The associations between physical activity and falls may depend on the method used to asses PA. In the Osteoporotic Fractures in Men Study (MrOS), falls were collected by post-card every 4 months over 4.5±0.9 years and PA was measured by the Physical Activity Score for the Elderly (PASE score; quartiles: Q1=least active; Q4=most active).[105] Men in the two highest PA quartiles were at an increased risk of falling over 4 months vs. men in the lowest PA quartile (Q4 RR=1.18, 95% CI: 1.07-1.29; Q3 RR=1.10, 95% CI: 1.01-1.20). However, in men aged ≥65 years from MrOS, physical activity from the Sensewear Armband (accelerometer) was associated with fall risk and the direction of the relationship depended on age.[104] The oldest old men (≥ 80 years) were at higher risk of falling at lower activity levels and higher sedentary activity, whereas "young old" men (≥65 but <80 years) were at higher risk of falling at higher levels of activity. "Young old" men with higher levels of physical activity may be participating in activities that have higher likelihood of falling, though was not evaluated in this study. Men with the lowest levels of activity were at increased risk of fracture compared to men with higher levels of activity, though no interaction existed between physical activity and age for fractures in older men. The relationship between physical activity and falls may follow a J-shape or U-shape curve where both very low and very high levels of physical activity are related to increased fall risk. However, the studies with high physical activity related to increased fall risk measured physical activity using self-reported questionnaires, whereas lower levels of physical activity were associated with increased fall risk when objectively measured using an accelerometer. The different methodologies for assessing physical activity could account for the inconsistent results across studies. Using both subjective and objective measures of physical activity may more accurately assess and refine the association between physical activity and falls.

The relationship between physical activity and falls may be bidirectional as falls may also be associated with future physical activity levels. Physical activity was measured with the Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire for recreational/leisure activity and household/yard work[106] and frequent falls was defined as a self-reported fall at all three interview assessments. Physical activity declined over one year of follow-up in men with frequent falls, but not in women. However, the starting PA levels were higher in men compared to women, which may explain why a change in PA was not seen in women since women were already at low levels of PA. Because the relationship between physical activity and falls may be bidirectional, the timing of the physical activity measure is extremely important to consider when studying risk factors of falls and fall injuries in cross-sectional studies of older adults. The physical activity measure may be influenced by fall status. For these reasons, the association between physical activity and falls and fall injuries may impact the intervention programs and physical activity recommendations targeted at older adult populations.

Table 2. Physical activity and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome and method; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – physical activity (PA)	Findings/results
Province et al. 1995[101]	N ranges: 100-1323 7 sites of the FISCIT trials	Mean age range: 73-88 % women range: 42-81% % white range: 72-100% All U.S.	Fall frequency Fall injury Self-reported; Injury is fracture or soft-tissue injury requiring medical care or resulting in significant impairment for ≥1 week; 18 fracture questions; 6 other injury questions Median follow-up range: 0.88-1.69 years	Ability to walk Functional dependence in >2 ADLs Balance deficits Lower extremity weakness	igh risk of falling	General exercise Resistance Balance Endurance Flexibility	↓ fall risk for interventions with: General exercise (IR=0.90; 95% CI: 0.81-0.99) Balance (IR=0.83; 95% CI: 0.70-0.98). NS for fall injury (power was low)
Buchner et al. 1997[102]	105	75 51% women 93% white	≥1 fall Self-reported Median follow-up time 18 months; maximum 25 months	Mild deficits in strength & balance		Strength training with weight machines, endurance training on bicycles & strength & endurance training Supervised (1 hr	↓ fall risk (HR=0.53; 95% CI: 0.30-0.91)

Table 2 Continued							
						session 3/wk) for 24-26 wks followed by self-supervised exercise	
Faulkner et al. 2009[103]	8,378 SOF	71±3	Incident fall rates (# falls/woman-yrs) from self-report Postcards & telephone calls every 4 months 4 years.	33% with ≥ 1 IADL impairment		Energy expenditure, kcal: modified Harvard Alumni Questionnaire; recreational PA. frequency & duration; blocks walked; stairs climbed in past year; # of hours/wk doing heavy household chores; # of hours/day spent lying & sitting	↑ fall risk vs. Q1 for: Q4 (RR=1.26; 95% CI: 1.10-1.44) Q3 (RR=1.12; 95% CI: 1.01-1.25) NS for Q2 vs. Q1 PA & IADL impairment interaction: IADL impairment ↑ fall risk for high median PA (RR=1.31; 95% CI: 1.14-1.52) NS for no IADL impairment
Cauley et al. 2013[104]	2,731 MrOS	78.9±5.1 0% women 90% white; 10% other U.S.	Self-reported # of falls in 1 year Self-reported fractures; adjudicated with medical records; follow-up 3.5±0.9 yrs Self-report on questionnaires mailed every 4 months	Ability to walk unassisted		*SenseWear Pro Armband* Total EE (kcal/d) Active EE =. energy expended at ≥ moderate intensity level Minutes per day spent in sedentary (METs ≤1.5), moderate (METs 3-<6) and vigorous (METs >6) intensity activities	Men < 80 years Lower active EE ↓fall risk (25-47% lower risk of falling vs. most active, p trend=0.08) Moderate active EE ↓fall risk (25-47% lower risk of falling vs. most active, p trend=0.08) Men ≥ 80 years Lowest active EE ↑ fall risk RR=1.43; 95% CI: 0.90- 2.26 (p trend= 0.09)

Table 2 Continued							
Chan et al. 2007[105]	5,867 MrOS	73.7±5.9 0% women 90% white; 10% other U.S.	≥1 fall Post-card every 4 months 4.5±0.9 years	Ability to walk unassisted		Physical activity (quartiles of PASE score: 1=least active, 4=most active)	↑ risk of fall for: Quartile 4 vs. 1 (RR=1.18; 95% CI: 1.07-1.29) Quartile 3 vs. 1 (RR=1.10; 95% CI: 1.01-1.20) NS for Quartile 2 vs. 1
Stahl & Albert 2015[107]	1,487 Falls Free Pennsylvania	75.5 ± 8.3 80% women 90% white	3-level variable (# of falls): Frequent: ≥3 Intermittent: 1-2 No falls Self-report at baseline, 6 months & 1 year			CHAMPS groups (1) recreational/ leisure; (2) household/ yard work; (3) walking; (4) aerobic/ exercise; (5) non-mobility	Men: - ↓ in. recreational/leisure & household/yard work for frequent fall group - NS in CHAMPS groups 1 or 2 for frequent, intermittent or no fall groups - NS in CHAMPS groups 3, 4 or 5 for frequent, intermittent or no fall groups Women: - NS in any CHAMPS group for frequent, intermittent or no fall

5.1.3 Body Mass Index and Obesity

Obesity measured by Body Mass Index (BMI) may be related to falls in older adults (Table 3). BMI is an indirect measure of body fat that can be used to estimate healthy weight in older adults. BMI is calculated as weight in kilograms divided by the square of height in meters (kg/m2) is used to screen for the following weight categories: underweight: BMI <18.5 kg/m2; healthy: BMI 18.5 to 24.9 kg/m^2, overweight: BMI 25.0 to 29.9 kg/m^2, obese: BMI 30.0 to 39.9 kg/m^2 or extreme/high risk obese: BMI >40.0 kg/m^2. Obese (BMI ≥30.0 kg/m^2) older adults were approximately 33% more likely more likely to have at least 1 fall[108,109] or at least 2 falls[109] compared to normal weight (18.5–24.9 kg/m^2) older adults.[108,109] Obesity was separated into 3 categories (obese category 1 BMI 30.0–34.9 kg/m^2; obese category 2 BMI 35.0–39.9 kg/m^2; obese category 3 BMI ≥40.0 kg/m^2). While all obese older adults have increase odds of falling, the odds of falling compared to normal weight increases with BMI level (12% for obese 1; 26% for obese 2; 50% for obese 3).[110] Obese older adults may be more likely to fall due poor balance as a result of obesity and comorbidities, such as diabetes and arthritis. However, BMI is an indirect measure of body fat and more direct measures of body fat, such as dual energy x-ray absorptiometry (DXA), may better classify older adults into appropriate obesity categories compared to self-report or height/weight measurements. These more direct measures of body fat may be more sensitive predictors of falls or fall injuries in older adults.

The weight categories used may result in different estimates of fall injury risk when examining the association between BMI and fall injuries. When BMI was classified as normal weight (18.5–24.9 kg/m2), overweight (25.0–29.9 kg/m2) and obese (≥30.0 kg/m2), BMI was not significantly associated with fall injury.[108,109] However, when BMI was classified into 5-

levels (underweight BMI < 18.5 kg/m^2; normal weight BMI 18.5–29.9 kg/m^2; obese category 1 BMI 30.0–34.9 kg/m^2; obese category 2 BMI 35.0–39.9 kg/m^2; obese category 3 BMI ≥40.0 kg/m^2), only the most obese older adults (class 3) had lower odds of sustaining a fall injury compared to those with normal weight. Extremely obese older adults may be less likely to experience a fall injury requiring medical attention due to the extra tissue surrounding the bones, which may be protective of fracture. However, type of injury was not examined in any of these studies. While obese older adults may be less likely to fracture, they may be more likely to experience non-fracture fall injuries or less serious injuries that do not require medical attention. Future studies examining type of fall injury in older adults should consider BMI and obesity because of its potential confounding effect on both falls and fall injury and since obese older adults may have different fall injuries than most studies have considered.

Table 3. BMI and obesity and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome and method; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – Body Mass Index (BMI)	Findings/results
Handrigan et al. 2017[108]	15,860 6399 men and 9461 women 2008–2009 Canadian Community Health Survey-Healthy Aging (CCHS-HA)	65-74: 55% 75–84: 36% ≥85:11% 60% women	≥1 fall ≥1 fall injury Self-reported in the past 12 months Fall serious enough to limit some of the respondent's normal activities Fall injury requiring health care utilization (medical attention, hospitalization)			Underweight <18.5 kg/m^2 Normal weight 18.5–24.9 kg/m^2 Overweight 25.0–29.9 kg/m^2 Obese ≥30.0 kg/m^2 Self- reported	<u>≥1 fall</u> Men: ↑ fall risk in obese vs. normal OR=1.33; 95% CI: 1.04-1.70 ↑ fall risk in obese vs. overweight OR=1.39 95% CI: 1.07–1.81 NS for underweight & overweight vs. normal NS for underweight & normal vs. overweight NS in women for underweight, overweight & obese vs. normal; NS in women for underweight, normal & obese vs. overweight <u>≥1 fall injury</u> NS for. underweight, overweight & obese vs. normal; NS for. underweight, normal weight & obese vs. overweight
Mitchell et al. 2014[109]	3,454 2009 New South Wales Falls Prevention Baseline Survey	≥65 Women & men	≥1 fall ≥2 falls Fall injury, Fall with hospital visit, Falls with hospital admission,			Healthy weight 18.5–24.9. kg/m^2 Overweight 25–29.9. kg/m^2 Obese ≥30. kg/m^2	<u>≥1 fall</u> ↑ risk for obese vs. normal weight: RR=1.31; 95% CI: 1.14-1.50 NS for overweight vs. normal weight <u>≥2 falls</u> ↑ risk for obese vs. normal weight Obese RR=1.32; 95% CI: 1.14-1.50

Table 3 Continued			Falls with medical treatment Self-reported in past 12 months				NS for overweight vs. normal weight <u>Fall with injury, hospital visit, hospital admission or medical treatment</u> NS for overweight & obese vs. healthy weight
Himes et al. 2012[110]	Health and Retirement Study (HRS)		1 fall Injury requiring medical treatment Self-report in past 2 years			Underweight < 18.5 kg/m^2 Normal weight 18.5–29.9 kg/m^2 Obese 1 30.0–34.9 kg/m^2 Obese 2 35.0–39.9 kg/m^2 Obese 3 ≥40.0 kg/m^2	<u>↑ risk of 1 fall vs. normal weight for:</u> Obese 1 OR=1.12; 95%CI: 1.01-1.24 Obese 2 OR=1.26; 95%CI: 1.05–1.51 Obese 3 OR=1.50; 95%CI: 1.21–1.86 NS for underweight vs. normal weight <u>↓ risk of fall injury vs. normal weight for:</u> Obese 3 OR=0.62 95% CI: 0.44–0.87 NS for underweight, obese 1 & obese 2 vs. normal weight

5.2 Fall, Fall Injury and Fracture History

Falls, recurrent falls and a previous fall injury including fracture within the past year have been identified as risk factors for future falling among older adults (Table 4). Self-reported history of any fall in the past year was associated with an increased risk of ≥1 fall (RR=1.86; 95% CI: 1.52-2.28)[111] and fracture (non-vertebral fracture HR=1.54; 95% CI: 1.22-1.96; lower extremity fracture HR=1.91; 96% CI: 1.36-2.67).[103] In a systematic review of 16 studies of the risk factors for falling, previous falls was among the strongest risk factors. for falling (adjusted RR range: 1.9-6.6; adjusted OR range 1.5-6.7).[112] Self-reported history of recurrent falls was associated with an increased risk of. ≥2 falls (OR=5.5; 95% CI: 3.9–7.9)[113] , ≥3 falls (RR=2.4; 95% CI: 1.3-4.4)[114] and fracture (non-vertebral HR=1.81; 95% CI: 1.40-2.34; head/chest HR=2.22; 95% CI: 1.42-3.49; upper-extremity HR=2.08; 95% CI: 1.01-4.28; lower-extremity HR=1.79; 95% CI: 1.23-2.61; hip HR=1.79; 95% CI: 1.07-2.98). [103] A self-reported fall injury (fracture , major laceration dislocation , bruise, abrasion, and other minor soft-tissue injury) in the past year was associated with and increased risk of ≥2 falls (RR=3.1; 95% CI: 1.5-6.4).[114] Adjusting for history of falls or fall injuries in studies of incident fall events may be an over-adjustment if fall history is related to other variables in the analyses, though this was not assessed. Previous fall events may predict future fall events, non-fracture fall injuries.

Low bone mineral density (BMD) is used to define osteoporosis and may lead to fractures after minimal trauma, such as a fall to the ground. In the U.S., a T-score of ≤−2.5 at the lumbar spine, femur neck, or total hip for BMD testing is used to define and diagnose osteoporosis. Other BMD cut-points have been used in studies of BMD and falls in older adults, such as T-score of ≤ (-1.8) or a 1 SD lower BMD. In a meta-analysis of 11 studies with approximately 90,000 person-years of follow-up that included various BMD measures predicting hip, wrist, spine, or all fractures, relative risks estimates, 1SD lower BMD at any site was associated with all fractures (RR=1.5; 95% CI: 1.4-1.6).[115] The relationships were stronger for spine BMD predicting risk of spine fracture (RR=2.3; 95% CI: 1.9-2.8) and hip BMD predicting hip fractures (RR=2.6; 95% CI: 2.0-3.5). In the SOF study,[116] similar results were found for the relationships between spine BMD and spine fracture (RR=2.1; 95% CI: 1.8–2.4) and between femoral neck BMD and hip fracture (RR=2.4; 95% CI: 2.1–2.7). Women with osteoporosis defined by T-score <-1.80 had an increased risk of ≥ 2 falls at 6 months (OR=3.46; 95% CI: 1.30, 9.24) and at 12 months (OR=2.04; 95% CI: 1.05, 3.98). No association between osteoporosis and recurrent falls was found for men. Approximately 53% of men and women fell, though the prevalence of osteoporosis for men and women is not clearly presented. Prevalence of osteoporosis tends to be higher in women (15% in US women and 4% in US men),[117] with higher estimates in Taiwanese populations (35% in women; 15% in men).[118] With the low sample size of men (n=204), the study may not have been adequately powered as an estimated 30 men had osteoporosis in this study. Osteoporosis or low BMD may have an association with falls in older adults, though only for women. Future research should validate these findings and identify underlying mechanisms between osteoporosis and the risk of falls and non-fracture fall injuries.

Table 4. History of falls/fall injury/fracture and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome and method; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – fall, fall injury and fracture history	Findings/results
Nevitt et al. 1989[114]	325	≥60 82% women 82% white U.S.	1 fall ≥2 falls Weekly calendar 1 year Injury: fracture, major injury (laceration with suture, dislocation) laceration without suture bruise, abrasion, other minor soft-tissue injury		Self-report of ≥1 fall in past year	Self-reported history of ≥3 falls in past year Self-reported fall injury in past year	NS for 1 fall ↑ risk of ≥2 falls for: ≥3 falls in past year (RR=2.4; 95% CI: 1.3-4.4) ≥1 fall injury in past year (RR=3.1; 95% CI: 1.5-6.4)
Coleman et al. 2004[113]	2,002 SOF	76±5 Women U.S.	≥2 falls Post-card every 4 months 1 year	Ability to walk unassisted		History of frequent falling at follow-up exam	↑ odds of ≥2 falls (OR=5.5; 95% CI: 3.9–7.9)
Vellas et al. 1998[111]	405	74±7 59% women 96% white; 4% other	≥1 fall Fall injury Report via phone & bimonthly postcards			Self-reported history of any fall	↑ risk of ≥1 fall (RR=1.86; 95% CI:1.52-2.28) NS for fall injury

Table 4 Continued		U.S.	1.83 years				
Faulkner et al. 2009[103]	5,995 MrOS	73.7±5.9 0% women	Fracture: Non-vertebral Head/chest Upper extremity Lower extremity Hip Questionnaire every 4 months; phone interview for date/time & location/source of medical care; verified by a physician adjudicator w/ medical records & radiographs; uncertainties adjudicated by the Clinical Outcomes Committee			Self-reported # of falls in past year: 0 1 ≥2	1 fall vs. 0 falls, ↑ risk for: Non-vertebral (HR=1.54; 95% CI: 1.22-1.96) Lower extremity (HR=1.91; 96% CI: 1.36-2.67) NS fall risk for head/chest, upper extremity & hip fractures ≥2 fall vs. 0 falls, ↑ risk for: Non-vertebral (HR=1.81; 95% CI: 1.40-2.34) Head/chest (HR=2.22; 95% CI: 1.42-3.49) Upper extremity (HR=2.08; 95% CI: 1.01-4.28) Lower extremity (HR=1.79; 95% CI: 1.23-2.61) Hip (HR=1.79; 95% CI: 1.07-2.98)
Tinetti & Kumar 2010[112]	Systematic review 16 studies		Fall	Communit y-dwelling		Previous falls	Adjusted RR range: 1.9-6.6 Adjusted OR range 1.5-6.7
Lin et al. 2013[119]	651 total 447 women 204 men	Women: 77.6±6.7 Men: 78.1±6.7 69% women; 31% men Taiwan	≥ 2 falls (≥ 1 at 6 mos & ≥1 at 12 mos) Self-report by phone or postcard; phone calls to participants at 1-			Osteoporosis T-score < -1.80 No Osteoporosis T-score ≥ -1.80 Quantitative ultrasound of left	Women: ↑ risk of ≥ 2 falls in women: At 6 months OR=3.46; 95% CI: 1.30, 9.24 At 12 months OR=2.04; 95% CI: 1.05, 3.98 Men:

Table 4 Continued			month intervals			heel	NS risk of ≥ 2 falls at 6 or 12 months
Marshall et al. 1996[115]	90,000 person-years 2,000 fractures Meta-analysis of 11 prospective studies	Mean age at study entry range: 57-83 (*not specified in 2 studies*) 100% women	Fractures that occurred after baseline bone density measurement Follow-up range: 1.8-24 years		Not treated for bone or hormonal-related disorders	Bone density from absorptiometry (single or dual energy, photon or x ray), QCT, MRI or ultrasound	↑ risk of fracture for 1 SD decrease in bone density below age-adjusted mean for: Forearm: RR=1.6; 95% CI: 1.5-1.7 Hip: RR=2.0; 95% CI:1.7-2.4 Vertebral: RR=2.1; 95% CI:1.9-2.3 All fractures: RR=1.5; 95% CI: 1.4-1.6 *BMD at the spine seemed to have a better predictive ability for spine fractures (RR=2.3; 95% CI: 1.9-2.8), BMD at the hip was better for predicting hip fractures (RR=2.6; 95% CI: 2.0-3.5)*
Stone et al. 2003[116]	7,238 for peripheral BMD 6,892 for central BMD SOF		Incident spine fractures Phone call or mailed questionnaire every 4 months; participants asked to notify clinical center ASAP after fracture Fractures radiographically confirmed; baseline compared to repeat			Peripheral BMD (distal and proximal radius and calcaneus) were made using single photon absorptiometry (Osteoanalyzer; Dove Medical Systems) Central BMD BMD of the proximal femur and	Peripheral BMD significantly associated with all fracture types except facial fractures: Significant RH range, per SD ↓ in BMD: RH=1.15; 95% CI: 1.02–1.30 to RH=2.44; 95% CI: 1.94–3.08 Central BMD significantly associated with all fracture types except face & ankle fractures Significant RH range, per SD ↓ in

Table 4 Continued			radiographs (~3.7 years later); fracture = ↓ in any vertebral height measure of ≥20% & 4 mm Follow-up ~10 years Exclude fractures from severe trauma (motor vehicle accidents, being struck by a car or other rapidly moving projectile, or assault)			subregions (introchanter, trochanter, femoral neck, and Ward's triangle), and of the lumbar spine in the anteroposterior (AP) projection using DXA (QDR 1000; Hologic, Waltham, MA, USA)	BMD: RH=1.20; 95% CI: 1.04–1.39 RH=2.50; 95% CI: 1.82–3.44

5.3 Musculoskeletal Pain and Symptomatic Osteoarthritis

Pain is a common complaint of older adults and can have a negative impact on health and quality of life, including increased risk of falls (Table 5). In older women with ≥1 difficulty in ≥2 function domains (lower extremity mobility, upper extremity function, IADLs, ADLs), pain was measured and classified as (1) no pain or mild pain at one site, (2) other pain (3) moderate to severe pain in the lower extremities or (4) widespread pain.[120] Women with other pain and widespread pain had an increased risk of ≥1 fall, recurrent falls (≥2 falls) and fracture from a fall vs. women with no pain or mild pain at 1 site. Women with moderate to severe pain in the lower extremities did not have increased risk of the fall outcomes vs. women with no pain or mild pain at 1 site. It is likely from these finding that women with high levels of pain are inactive due to the pain and therefore not at increased exposure to falling. These results may not apply to healthier older adults, as all participants had some functional difficulty. In MrOS, any pain was defined as pain in the past 4 weeks that interfered with normal work moderately, quite a bit or extremely, and no pain included those who reported no pain or pain that interfered with normal work a little bit.[121] Hip and knee pain in the past year on most days were also assessed. Men who reported any pain, hip pain and knee pain were at increased risk of ≥1 fall and ≥2 falls. Pain was not associated with hip or non-spine fracture. Any pain included moderate, quite a bit and extreme pain though men with extreme pain may be different than those with moderate pain. Including all pain groups into one level may result in lower estimates compared to other pain classifications that separate out groups. Methodological differences in these studies, including varying methods for measuring pain due to lack of a standard pain assessment, makes it challenging to fully understand pain as a risk factor for falls and fall injuries.

Painful in the joints can cause decreased range of motion and may increase risk of falls and fall injuries in older adults. Pain as the most commonly reported symptom of osteoarthritis, which is defined as painful inflammation and stiffness of the joints that can cause decreased range of motion. In adults ≥60 years (82% women) who self-reported ≥1 fall in past year,[114] self-reported arthritis (yes/no) was associated with an increased risk of recurrent falls (≥2 falls) over 1 year, though not associated with 1 fall over 1 year. Falls were assessed using weekly calendars, but it is unclear if strategies were implemented for those who did complete the calendars, such as phone calls, to reduce non-respondent rates and bias. Older Mexican-Americans who self-reported arthritis had increased odds of at least 1 fall in past year compared to those without arthritis.[122] In the Duke EPESE study, those with arthritis had increased odds of at least 1 fall and recurrent falls (≥2 falls) in the past year.[27] In the 2012 Behavioral Risk Factor Surveillance System (BRFSS) survey, the age adjusted mean prevalence of any fall, 1 fall, ≥2 falls and fall injury was higher in adults with arthritis (self-reported doctor or other health professional diagnosis of arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia) compared to those without arthritis.[123] Arthritis was self-reported in all studies and prevalence of the disease may have been either overestimated if any of the older adults with joint pain but without physician diagnosis reported having arthritis. The studies did not include arthritis symptoms, such as decreased range of motion, though this is significant to measure in studies of falls and fall injuries. Decreased range of motion, especially in the lower extremities, may lead to inability to move the hip/knee joints in order to maintain balance after tripping or slipping, thus causing inability to prevent a fall. Subclinical imagining can be used to confirm arthritis, though studies of arthritis and fall and fall injury should include symptoms and location of the disease, since the pain symptom is associated with falls.

Table 5. Musculoskeletal pain and symptomatic osteoarthritis and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome and method follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – musculoskeletal pain & osteoarthritis	Findings/results
Leveille et al. 2002[120]	940 WHAS	78 100% women 71% white; 29% black U.S.	≥1 fall ≥2 falls Fracture Self-report at in-home interviews every 6 months. 3 years	≥1 difficulty in ≥ 2 function domains (lower extremity mobility, upper extremity function, IADLs, ADLs)	No moderate to severe cognitive impairment (MMSE≥ 18)	Pain No/mild 1 site; Other; Moderate/severe in legs; Widespread Assessed at baseline	↑ odds of ≥1 falls: Other (OR=1.36 95% CI: 1.02-1.82) Widespread (OR=1.66; 95%CI: 1.25-2.21) ↑ odds of ≥2 falls: Other (OR=1.54; 95% CI: 1.01-2.35) Widespread (OR=1.66; 95% CI: 1.10-2.50) ↑ odds of fracture from fall: Other (OR=2.97; 95% CI: 1.45-6.08) Widespread (OR=2.32; 95% CI:1.06-5.04)
Munch et al. 2015[121]	5,993 MrOS	74±6 0% women 90% white	≥1 fall ≥2 falls Hip fracture Non-spine fracture Self-reported on postcards every. 4 months Falls over 1 year			Any pain (yes/no) Hip pain (yes/no) Knee pain (yes/no) SF-12 questions: Any pain in past 4 weeks that. interfered with normal work moderately, quite a bit & extremely (options not at all and a little bit in no	↑ risk of ≥1 fall for: Any pain OR=1.7; 95% CI: 1.4-1.9 Hip Pain OR=1.3; 95% CI: 1.1-1.5 Knee pain OR=1.4; 95% CI: 1.3-1.7 ↑ risk of ≥2 falls for: Any pain OR=2.0; 95% CI: 1.7-2.4 Hip Pain OR=1.5; 95% CI: 1.2-1.8

Table 5 Continued.							
			Fractures for ~8 years; centrally adjudicated by physician with medical records			pain group) Hip/knee pain in past 12 months on most days for ≥1 month	Knee pain OR=1.8; 95% CI: 1.5-2.1 NS for hip or non-spine fracture for any pain, hip pain or knee pain
Nevitt et al. 1989[114]	325	≥60 82% women 82% white; 18% other U.S.	1 fall ≥2 falls Weekly calendar 1 year		Self-report of ≥1 fall in past year	Arthritis	NS for 1 fall ↑ risk of ≥2 falls (RR=2.7; 95% CI: 1.3-5.6)
Reyes-Ortiz et al. 2004[122]	1391; Hispanic EPESE	77 61% women 100% Mexican Americans U.S.	≥1 fall Self-report of falls in past year 1-2 years			Arthritis	↑ odds of ≥1 fall (OR=1.32; 95% CI:1.04-1.68)
Hanlon et al. 2002[27]	2,996 Duke EPESE	72.3±5.8 64% women 35% black; 65% white U.S.	≥1 fall ≥2 falls Self-reported in past 12 months			Arthritis	↑ odds of ≥1 fall (OR=1.59; 95%CI: 1.28-1.98) ↑ odds of ≥2 falls (OR=2.19; 95%CI: 1.57-3.05)
Barbour et al. 2014 [123]	338,734 2012 BRFSS	≥45 (*similar fall prevalence for 45-64 and ≥65 &*	≥1 fall vs. no fall 1 fall & ≥2 falls vs. no fall			Self-report of a doctor or other health professional diagnosis of arthritis,	For arthritis vs. no arthritis (relative differences), age-adjusted median prevalence of:

Table 5 Continued		*did not report ≥65 separately*)	Fall injury vs. no injury Self-reported in past 12 months; injury that limited regular activities for ≥1 day or required doctor visit			rheumatoid arthritis, gout, lupus, or fibromyalgia	≥1 fall: 79% 1 fall: 28% ≥2 falls: 137% Fall injury: 149%

5.4 Aging Diseases

5.4.1 Diabetes

Older adults with diabetes may also be at an increased risk of falls and fall injuries (Table 6). Type 2 diabetes (T2D) is a disease that affects the body's ability to produce or use insulin and can cause complications such as peripheral neuropathy, reduced vision, and impaired renal function. Overall, self-reported diabetes was associated with an increased fall risk (OR ranges from 1.4-2.8).[27,122,124] These studies relied on self-reported diabetes and approximately 28% of those with diabetes in the U.S. are undiagnosed (CDC, 2014 National Diabetes Statistics Report). Therefore, the risk of falls may have been underestimated in these studies if undiagnosed diabetes is associated with falls. Using diabetes definitions that include clinical tests of diabetes, for example through glucose tolerance or fasting glucose tests, may provide more accurate estimates of the association between diabetes and falls as those who are undiagnosed will be identified through these tests and classified correctly.

Diabetics treated with insulin therapy may have an increased risk of falls due to experiencing more hypoglycemic episodes. Insulin therapy is a common treatment for type 2 diabetes in those with severe hyperglycemia. In older diabetic adults in the Health Aging and Body Composition (Health ABC),[125] glycemic control (A1C≤6%) through insulin therapy was associated with falling (OR=4.10; 95% CI: 1.24, 13.54), though glycemic control with oral hypoglycemic medications did not increase fall risk. Also in Health ABC,[126] the risk of fall injury requiring hospitalization was higher in those with any diabetes (HR=1.41; 95% CI: 1.05-1.88) and those with insulin-treated diabetes (2.24; 95% CI: 1.24-4.03) vs. those with no diabetes. Older adults with diabetes but no insulin treatment were similar in terms of fall injury requiring hospitalization risk compared to those with no diabetes. These results indicate that low A1C levels may be achieved through use of oral hypoglycemic medications without increasing risk of falls or fall injuries using, though not for insulin. Diabetes should be considered as a confounder in studies of falls and fall injuries in older adults. Few studies have included insulin therapy when considering diabetes, though since those taking insulin to treat diabetes may be at an increased risk of falls or fall injury, diabetes definitions that include treated diabetes should also be considered in studies of falls and fall injuries in older adults. Further, studies including hypoglycemic agents in the diabetes definitions should separate this class of medication based on insulin vs. oral hypoglycemic medications.

Type 2 diabetes has been associated with increased risk of hip fractures. Two recent meta-analyses of diabetes and hip fracture risk found an increased risk of hip fracture in those with T2D (RR=1.4; 95% CI: 1.3–1.5; RR=1.7; 95% CI: 1.3–2.2) vs. those with no diabetes.[127,128] The pathophysiology and mechanism for increased fracture risk in type 2 diabetics has not been well established though could be due to body composition, diabetes complications, hormonal changes and medications.[129] Studies of falls and fractures from falls should include diabetes as this condition may confound the associations between risk factors and falls and fractures.

Table 6. Diabetes and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome and method; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – Diabetes	Findings/results
Reyes-Ortiz et al. 2004[122]	1391; Hispanic EPESE	77 61% women 100% Mexican Americans in U.S.	≥1 fall Self-report of falls in past year 1-2 years			Self-reported of physician diagnosis.	↑ odds of ≥1 fall (OR=1.37; 95% CI:1.06-1.77)
Schwartz et al. 2002[124]	N=5,430 SOF	74 100% women U.S.	Average of >1 fall/year Postcard every 4 months; phone calls for non-returned cards 7.2±1.9. years			Self-reported of physician diagnosis & current insulin use	↑ odds of >1 fall/year for insulin-treated diabetes (OR=2.76; 95% CI: 1.52–5.01) NS for non-insulin treated diabetes
Hanlon et al. 2002[27]	2,996 Duke EPESE	72.3±5.8 64% women 35% black; 65% white U.S.	≥1 fall ≥2 falls Self-reported in past year			Self-reported diabetes	↑ risk of ≥1 fall (OR=1.36; 95%CI: 1.04-1.79) ↑ risk of ≥2 falls (OR=1.46; 95%CI: 1.02-2.08)
Schwartz et al. 2008	446 Health ABC	73.6 ± 2.7 45% women 53% white	Continuation ratio model for ordinal number of falls variable (Modeled as a sequence of dichotomous outcomes: 1st, any falls vs none; then among those with		Diabetes Self-reported of physician diagnosis, hypoglycemic medication use, or elevated fasting glucose	A1C >8% (referent) 7%<A1C≤8% 6%<A1C≤7% A1C≤6%	relative ↑ in odds of continuation for A1C≤6% vs. A1C >8% OR=4.10; 95% CI: 1.24, 13.54 NS for 7%<A1C≤8% vs. A1C >8% NS for 6%<A1C≤7% vs. A1C >8% NS among those not using insulin for all A1C levels vs. A1C >8%

Table 6 Continued			≥1 fall, ≥2 vs 1; and so forth. Self-reported number of falls (1, 2-3, 4-5, or ≥6) in past 12 months; follow-up 4.9 (range 2.9-5.4) years.		(≥126 mg/dl) or 2-hour oral glucose tolerance test (OGTT) (≥200 mg/dl).		
Yau et al. 2013[126]	3,075 Health ABC	74±3 52% women 42% black; 58& white U.S.	Fall injury resulting in hospitalization (ICD-9 codes) 10.1±3.5 years	No mobility disability		Diabetes (self-report of physician diagnosis/self-report antidiabetes meds / ↑ fasting glucose (≥126 mg/dL)/ ↑ levels on 2 hour oral glucose tolerance test (≥200 mg/dL)	↑ risk of fall injury requiring hospitalization: Any diabetes vs. no diabetes (HR=1.41; 95% CI: 1.05-1.88) Diabetes, insulin vs. no diabetes (HR=2.24; 95% CI: 1.24-4.03) NS for diabetes, no insulin vs. no diabetes & vs. diabetes, insulin
Vestergaard et al. 2007[127]	Meta-analysis 8 studies						↑ risk of hip fracture. for T2D vs. no diabetes (RR=1.4; 95% CI: 1.3–1.5)
Janghorbani et al. 2007[128]	Meta-analysis 12 studies						↑ risk of hip fracture. for T2D vs. no diabetes (RR=1.7; 95% CI: 1.3–2.2)

5.4.2 Hypertension and Hypotension

Declines in blood pressure can reduce cerebral perfusion that can impair consciousness, lead to dizziness, changes in balance, and increase the likelihood of a fall (Table 7). Orthostatic hypotension (OH) refers to a significant decrease in blood pressure upon assuming an upright posture. OH assessed via change in blood pressure after 3 minutes of tilting was associated with increased odds of an unexplained fall vs. no falls (OR=2.29; 95% CI: 1.07–4.90) and vs. a balance-related fall (OR=2.52; 95% CI:1.15–5.34). When utilizing varying OH definitions (blood pressure 1 minute after standing and 3 minutes after standing) and stratifying by hypertension status (controlled or uncontrolled), only those with OH 1 minute after standing and uncontrolled hypertension had increased fall risk (HR=2.5; 95% CI: 1.3–5.0). A review article that included 13 total studies found average 2-fold association between OH and falling (OR=2.2 or RR=2.3) across 9 studies. The other 4 studies found no association between the two variables. These inconsistencies may be the result of the measurement device used, type of orthostatic stress test, definition of orthostatic blood pressure changes, or method of ascertaining fall history.

Table 7. Orthostatic hypotension and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome; method to measure fall/fall injury; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor -. orthostatic hypotension (OH)	Findings/results
Menant et al. 2016[130]	529 Sydney Memory and Ageing Study (MAS)	79.8 ± 4.4 52% women Australia	≥1 fall unexplained fall ≥1 fall balance-related fall Monthly fall diaries with phone calls as required 1 year			OH: ↓ ≥20 mmHg in SBP or ≥10 mmHg in DBP within 3 mins of tilting	↑ odds of ≥1 unexplained fall: vs. 0 falls (OR=2.29; 95% CI:1.07–4.90) vs. ≥1 balance-related fall (OR=2.52; 95% CI:1.15–5.34)
Gangavati et al. 2011[131]	722 MOBILIZE Boston Study	78±5 64% women US	≥ 2 falls Monthly fall calendar with events adjudicated by geriatricians and investigators 1 year			OH: ↓ ≥20 mmHg in SBP or ≥10 mmHg in DBP within 3 mins of standing SOH: ↓ ≥20 mmHg in SBP within 1 & 3 mins of standing DOH: ↓ ≥10 mmHg in DBP within 1 & 3 mins of standing Uncontrolled hypertension: BP≥140/90 mmHg Controlled Hypertension: Antihypertensives/ BP<140/90 mmHg	NS for OH, SOH or DOH at 1 or 3 mins vs. no OH Stratified analyses Controlled hypertension: NS for SOH or DOH at 1 & 3 mins vs. no OH Uncontrolled hypertension: ↑ risk of ≥ 2 falls for SOH at 1 min (HR=2.5; 95% CI: 1.3–5.0 NS for SOH at 3 mins or DOH at 1 & 3 mins vs. no OH NS for uncontrolled or. controlled hypertension vs. no hypertension

Table 7 Continued							
Shaw et al. 2014[132]	Review article 13 studies	Range 70-4931	Fall 2 retrospective 9 prospective self-report 2 prospective incident reports			<u>OH definitions:</u> Consensus ↓ ≥20 mmHg in SBP and/or ≥10 mmHg in DBP 3 minutes after head up/standing Initial ↓ ≥40 mmHg in SBP and/or ≥20 mmHg in DBP 3 minutes after head up/standing 10 used consensus only; 2 used consensus + initial; 1 did not report definition	Average OR=2.2 or RR=2.3

5.4.3 Urinary Incontinence

Urinary incontinence (UI) is the loss of bladder control and can cause the sudden urge to urinate and may be related to falls (Table 8). With age, the bladder muscle weakens and loses storage capacity resulting in more frequent urination. Common types of UI in older adults are stress incontinence (leaking of urine with pressure on the bladder by coughing, sneezing, laughing, exercising or heavy-lifting) and urge incontinence (sudden, intense urge to urinate requiring frequent urination, including throughout the night). Due to the frequency and urgency to urinate, older adults with UI may be at higher risk of falls. Urge incontinence was associated with increased risk of falls (OR=1.26; 95% CI: 1.14-1.40) and fracture (HR=1.34; 1.06-1.69). Stress incontinence was not associated with falls or fracture. Urge incontinence may lead to frequent urges to urinate in the middle of the night, which may explain why those with urge and not stress UI were at increased risk of falls. Assessing falls circumstances including time of day the fall occurs among those with UI may explain a portion of the relationship of urge incontinence with falls in older adults.

Table 8. Urinary incontinence and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome; method to measure fall/fall injury; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – urinary incontinence (UI)	Findings/results
Nevitt et al. 1989[114]	325	≥60 82% women 82% white; 18% other U.S.	1 fall ≥2 falls Weekly calendar 1 year		Self-report of ≥1 fall in past year	Self-reported UI	NS for 1 fall NS for ≥2 falls
Brown et al. 2000[133]	6,049 SOF	78.5±24.6 100% women U.S.	≥1 fall Fracture Post-card every 4. months; radiographs confirmed fractures; phone call if post-cards not returned schedule 3 years			Self-reported urge and stress UI	↑ odds of ≥1 fall (urge) (OR=1.26; 95% CI: 1.14-1.40) ↑ hazards of fractures (urge) (HR=1.34; 95% CI: 1.06-1.69) NS for stress incontinence with. falls and fractures

5.4.4 Vision, Cognition, Depression, Stroke and Parkinson's Disease

Other subclinical measures and comorbid conditions associated with neurological function may be associated with fall and fall injury outcomes in older adults, including impaired vision, impaired cognition, depression, stroke and Parkinson's Disease (Table 9). In the Study of Osteoporotic Fractures (SOF) study of women aged 76.4±4.8 years, visual acuity, a measure of vision sharpness measured by the ability to discern letters at a given distance, was measured to assess vision.[113] Women with worse vision (1-5, 6-10, 11-15 or >15 letters lost) were more likely to have ≥2 falls (OR=2.08; 95% CI: 1.39–3.12; OR=1.85; 95% CI: 1.16–2.95; OR=2.51; 95% CI: 1.39–4.52; OR=2.08; 95% CI: 1.01–4.30). A review of 26 cognitive function and fall, fall injury and fracture studies (mean age range: 70.3-81.4) found that those with cognitive impairments (dementia or worse global cognition, executive function, immediate recall, verbal reasoning, non-verbal/abstract reasoning or processing speed) were at increased risk for any fall (OR=1.32; 95% CI: 1.18–1.49), fall injury (OR=2.33; 95% CI: 1.61–3.36) and fracture (RR=1.78; 95% CI: 1.34–2.37).[134] Depression from the Center for Epidemiological Studies Depression (CES-D) questionnaire was associated with increased risk of ≥ 1 fall. (OR=1.59; 95% CI:1.16-2.19)[122] and higher when measured with the Geriatric Depression Scale for both ≥1 unexplained fall (OR=4.43; 95% CI:1.71-11.47) and ≥1 balance-related fall (OR=3.41; 95% CI:1.29-9.00).[130] Self-reported stroke was associated with increased risk of ≥ 1 fall (OR=1.32; 95% CI: 1.07–1.64), though not associated with fall injury.[135] Self-reported Parkinson's Disease (PD) was associated with increased risk of ≥2 falls (RR=9.5; 95% CI: 1.8-50.1),[114] though the estimate was lower in MrOS (OR=2.30; 95% CI:1.15–4.59) and not independent of other confounding factors.[136] Vision, cognitive function, depression, stroke and Parkinson's Disease should be considered in studies of fall events in older adults.

Table 9. Vision, cognition, depression, stroke and Parkinson's Disease and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome; method to measure fall/fall injury; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor – cognitive function	Findings/results
Coleman et al. 2004[113]	2,002 SOF	76.4±4.8 100% women U.S.	≥2 falls Post-cards every 4 months 1 year	Ability to walk unassisted		Visual acuity: 0 letters lost (referent) 1-5 letters lost 6-10 letters lost 11-15 letters lost >15 letters lost	↑ odds of ≥2 falls: OR=2.08; 95% CI: 1.39–3.12 OR=1.85; 95% CI: 1.16–2.95 OR=2.51; 95% CI: 1.39–4.52 OR=2.08; 95% CI: 1.01–4.30
Tinetti et al. 1995[137]	1,103	72+ U.S.	Fall injury Fall calendars wit telephone interviews & surveillance of ER & hospital records for injury 31 months			Cognitive impairment	↑ odds of fall injury (OR=2.2; 95% CI: 1.5-3.2)
Muir et al. 2012[134]	Range: 81-2,005 26 studies	Mean age range: 70.3-81.4 Mean % women range: 50-100%	Any fall: 1 fall (1) ≥1 fall (13) ≥2 falls (6) Fall injury (5) Fracture (5) Fall calendar most common			Dementia diagnosis & severity; Global cognition; Executive function; Immediate recall; Verbal reasoning; Non-verbal/ abstract reasoning; Processing speed	*56% of studies had significant association with fall outcome* Summary of risk estimates: Any fall OR=1.32; 95% CI: 1.18–1.49 Fall injury OR=2.33; 95% CI: 1.61–3.36 Fracture RR=1.78; 95% CI: 1.34–2.37

Table 9 Continued			1-9.8 years follow up				
Reyes-Ortiz et al. 2004[122]	1391; Hispanic EPESE	77 61% women 100% Mexican Americans U.S.	≥1 fall Self-report of falls in past year 1-2 years			CES-D≥16	↑ odds of ≥1 fall (OR=1.59; 95% CI:1.16-2.19)
Menant et al. 2016[130]	529 Sydney Memory and Ageing Study (MAS)	79.8 ± 4.4 52% women Australia	≥1 unexplained fall ≥1 balance-related fall Monthly fall diary & phone calls over 1 year			Geriatric Depression Scale score ≥ 5	↑ odds of ≥1 unexplained fall: vs. 0 falls (OR=4.43; 95% CI:1.71-11.47) vs. ≥1 balance-related fall (OR=3.41; 95% CI:1.29-9.00)
Clemson et al. 2015[138]	904 Melbourne Longitudinal Studies on Healthy Ageing Program (MELSHA)	73.4 (65-94) 53 % women	≥1 fall injury Biennial in-person interview over 11 years; Self-report of injury requiring medical treatment			Psychogeriatric Assessment Scales (PAS; scale: 0-11)	↑ risk of ≥1 fall injury (HR=1.12; 95% CI: 1.05-1.20)
Grundstrom et al. 2012[135]	12,684 2008 Behavioral Risk Factor Surveillance System (BRFSS)	≥85 85-89: 73% 90-94: 20% 95+: 4% (3% missing age)	≥ 1 fall ≥ 1 fall injury (no injury includes fallers/no injury & non-fallers) ≥ 1 fall injury (no injury includes	38% with self-reported activity limitation due to health problems		Stroke from self-report; told by a. doctor, nurse, or other health professional	↑ risk of ≥ 1 fall vs. no fall (OR=1.32; 95% CI: 1.07–1.64) NS for ≥ 1 fall injury vs. no injury among fallers/no injury & non-fallers NS for ≥ 1 fall injury vs. no injury

Table 9 Continued		71% women 90% white U.S.	fallers/no injury only) Self-report in past 3 months via telephone Injury that limited regular activities for ≥1 day or led to. doctor visit				among fallers only
Nevitt et al. 1989[114]	325	≥60 82% women 82% white; 18% other U.S.	1 fall ≥2 falls Weekly calendar 1 year		Self-report of ≥1 fall in past year	Self-report Physician exam	NS for 1 fall NS for ≥2 falls NS for 1 fall ↑ risk of ≥2 falls (RR=9.5; 95% CI: 1.8-50.1)
Fink et al. 2005[136]	5,867 MrOS	74 0% women U.S.	≥2 falls Post-card every 4 months; 3.65 years	Ability to walk unassisted		Parkinson's disease	↑ odds of ≥2 falls (OR=2.30; 95% CI:1.15–4.59)

5.5 Medication Use

5.5.1 Fall-related Medications and Polypharmacy

Medications may be one of the most common and potentially reversible risk factors for falls in older adult populations as adverse medication effects such as unsteadiness, impaired alertness, and dizziness may lead to falls (Table 10). A meta-analysis of 40 observational studies of older adults found that psychotropic medications (benzodiazepines, antidepressants, sedative hypnotics, anticonvulsants, and neuroleptics) are associated with a 48-73% increased risk of falls (OR; 95% CI range: OR=1.48; 95% CI: 1.23-1.77 to 1.73; 95% CI: 1.52-1.97).[139] In a systematic review of 28 observational studies and 1 randomized clinical trial,[140] increased falls and fracture risk were found in the majority of studies for benzodiazepines (85% of studies), antidepressants (71% of studies), antipsychotics (67% of studies) and antiepileptics (75% of studies). Only 1 of 2 studies for opioids and 3 of 12 for antihypertensives found significant associations with falls and fractures. The only study of cholinesterase inhibitors found no association with falls and fractures. Several studies in the meta-analysis and review grouped chemically and often functionally unrelated medications into one category (e.g., psychotropics or sedative/hypnotics). Unrelated medications within these groups may have different effects on falls and fall injuries and these groupings may not have been appropriate. Dosage or duration of medication use was also not collected, though may be indicators of disease severity and may impact the estimates for fall and fall injury risk. Additionally, confounding by indication may exist as participants in these observational studies who were prescribed or took particular medications may have been inherently different from those who did not use the medication. Analytical approaches, such as propensity score matching, could be used to balance groups of those who take medications and those who do not on observed variables, thus reducing the impact of any inherent differences. Medications are particularly complex risk factors for falling as the underlying condition or disease for which the medication is being taken may also be a risk factor for falls and fall injuries, such as pain or depression. Using an overall total number of medications to assess medications may be a better approach in studies of older adults with multiple comorbid conditions and therefor, multiple medication use.

Total number of medications may be related to falls in older adults. In a study using the Kaiser Permanente Northern California Diabetes Registry (N=20,656; age ≥65 years), medications were defined as 1 filled prescription for a given medication for ≥30 days' supply within 6 months prior to baseline or over-the-counter use of antihistamines, aspirin, calcium, and magnesium.[141] Total number of medications categories for analyses were 0-1, 2-3, 4-5, 6-7 or >7. Individual glucose-lowering medications (insulin, sulfonylureas, and metformin) were also considered separately. Falls were defined using inpatient and outpatient diagnosis codes for falls (ICD-9 codes: E880-E888). Fractures from falls were defined by the same fall codes plus codes for fracture (ICD-9 codes: 733, 800-829, E887). Fall risk was higher in those taking 6-7 medications (HR=1.28; 95% CI: 1.05, 1.56) and those taking >7 medications (HR=1.39; 95% CI: 1.14, 1.70) compared to those taking 0-1 medication. No associations were found for 2-3 or 4-5 vs. 0-1 medications, or for any of the medication levels vs. 0-1 medication for the hypoglycemic agents separately. Risk estimates were not provided for falls resulting in a fracture. Polypharmacy may be a stronger predictor of fall events compared to any single medication. Fall-related medications and total number of medications must be considered confounding factors in studies of falls and fall injuries in older adults.

Table 10. Fall-related medication use and polypharmacy and falls/fall injury

Authors	Total N or N per group; study	Demographics: age (mean±SD or range), sex, race, country	Falls outcome; method to measure fall/fall injury; follow-up time	Functional status	Other chronic disease/ lifestyle risk factors	Risk Factor - medications	Findings/results
Leipzig et al. 1999[139]	Range: 47-3,494 Meta-analysis 40 observational studies	Mean age range: 67-89	≥1 fall 19 studies used self-report; 20 studies used incident reports; 1 not reported			Psychotropics, Neuroleptics, Sedatives/hypnotics, Antidepressants, Tricyclic antidepressants (TCAs), Neuroleptics, Benzodiazepines (long- & short-acting)	↑ pooled odds of ≥1 fall for use of: Psychotropics OR=1.73; 95% CI: 1.52-1.97 Neuroleptics OR=1.50; 95% CI: 1.25-1.79) Sedatives/hypnotics OR=1.54; 95% CI: 1.40-1.70 Antidepressants (mainly TCAs) OR=1.66; 95% CI: 1.4-1.95 Benzodiazepines OR=1.48; 95% CI: 1.23-1.77 Neuroleptics OR=1.50; 95% CI: 1.25-1.79
Hartikainen et al. 2007[140]	Range: 70-132,873 Review article 28 observational studies 1 RCT	60+	Fall (22) Fracture (7) Falls from fall calendars, phone calls, postcard, staff records & hospital registers 1 year			Drug (# of studies) Benzodiazepines (20) Antidepressants (17) Antipsychotics (9) Antiepileptics (4) Antihypertensive (12) Opioids (2) Cholinesterase inhibitors (1)	↑ fall & fracture risk (% of studies): Benzodiazepines (85%) Antidepressants (71%) Antipsychotics (67%) Antiepileptics (75%) Antihypertensive (25%) Opioids (50%) Cholinesterase inhibitors (0%)

Table 10 continued Marcum et al. 2016[142]	2,948 Health ABC	73.6 ± 2.9 52% women 41% black U.S.	≥2 falls Self-reported every 12 months	No mobility disability		Antidepressants: Any use Short duration Std daily dose 1-2 SSRIs	↑ odds of ≥2 falls (OR=1.48; 95% CI: 1.12-1.96) (OR=1.47; 95% CI: 1.04-2.00) (OR=1.59; 95% CI: 1.15-2.18) (OR=1.62; 95% CI: 1.15-2.28) * Stronger associations when stratified by history of falls/fractures
Ensrud et al. 2002[143]	8,127 SOF	77 100% women U.S.	≥1 fall ≥2 falls Post-card every 4 months or phone call 12 ±1.5 months			CNS meds	↑ risk of ≥1 fall for: Benzodiazepines (RR=1.34; 95% CI: 1.09-1.63) Anticonvulsants (RR=1.75; 95% CI: 1.13-2.71) NS for antidepressants & narcotics ↑ risk of ≥2 falls for: Benzodiazepines (RR=1.51; 95% CI: 1.14-2.01) Anticonvulsants (RR=2.56; 95% CI: 1.49-4.41) Antidepressants (RR=1.54; 95% CI: 1.14-2.07) NS for narcotics
Huang et al. 2010[141]	Total N=46,946 ≥65 N=20,656. (44% of total) Kaiser Permanente Northern California	61.56±12.16 *Reported results only for ≥65*	Incident falls Inpatient & outpatient diagnosis codes for falls (ICD-9 codes: E880-E888); + fracture codes. (ICD-9 codes: 733, 800-829, E887); 5 yrs follow-up			# of medications: 0-1 (referent) 2-3 4-5 6-7 >7 Prescribed medication defined as 1 filled prescription for a given medication, for ≥30	↑ risk of ≥1 fall for: 6-7 medications HR=1.28; 95% CI: 1.05, 1.56 >7 medications HR=1.39; 95% CI: 1.14, 1.70 NS for 2-3 or 4-5 vs. 0-1 medications NS for all medication levels vs. 0-1 medication for hypoglycemic agents separately

Table 10 Continued	Diabetes Registry					days' supply, within 6 months prior to baseline Most over-the-counter medications excluded, except antihistamines, aspirin, calcium, and magnesium. 2 physicians reviewed prescribed medications Individual glucose-lowering medications (insulin, sulfonylureas, & metformin) also considered separately	
Vellas et al. 1998[111]	405	74 ± 7 59% women 96% white; 4% other U.S.	≥1 fall Fall injury Call in falls/fall injuries; Bimonthly postcard 1.83 years			# of medications	NS for ≥1 fall ↑ risk of fall injury (RR=1.14 ; 95% CI: 1.02-1.26)

6.0 Associations Between Muscle Function and Physical Performance in Older Adults

Physical function includes whole body function (lower extremity function, upper extremity function, and neck and back function) and the ability to perform activities of daily living. Physical performance tests are objective measures of physical function. Walking tests, chair stand tests and balance tests are commonly used measures of physical performance in older adults. However, a single gold standard method for measuring physical performance does not exist. Because these physical performance tasks require the use of muscles, older adults with weaker muscle function may have worse physical performance. The studies examining the relationships between muscle function and physical performance have used varying measures of muscle function and physical performance, as well as, different protocols for each measure (Table 11; summary of results in Tables 12 and 13). Most studies of muscle function and physical performance used leg strength to measure muscle function in relation to physical performance, while others have used ankle strength or leg power as a measure of lower-extremity muscle function.

Keiser leg extension strength was related to physical performance, though protocols were not consistent across studies and relationships varied by population characteristics, such as sex and musculoskeletal pain. Overall, Keiser leg strength was related to balance, slower chair stands time and worse SPPB score. Results were mixed for usual walk gait speed as 2 studies showed that leg strength was associated with gait speed[144,145] while two found no association with gait speed.[64,146] Several factors may explain these differences, including pain and. the protocol used for testing.

Pain may affect the ability to perform some physical performance tests and may depend on pain location. Pain, a symptom commonly reported by older adults, and the location of the pain should be considered when selecting physical performance tests in studies of muscle function. One study found that lower leg strength was related to slower chair stands time. This relationship was stronger for those with back pain compared to those without back pain. No association with gait speed was found for leg strength regardless of back pain status[146]. Back pain may affect the ability to stand up from a chair, though other types of pain, such as foot or calf pain, may affect the ability to perform walking tasks more than the ability to stand up from a chair. Back pain was the only location assessed in this study and those without back pain may have had pain in other locations which affected ability to perform the walking tasks. In studies of muscle function and physical performance, pain assessments should include pain for all body locations involved in the physical performance tests. Pain should also be included as a potential confounder as pain may account for some of the relationship between muscle function and poor physical performance.

Establishing the 1 repetition maximum (1RM) is a key methodological component for measuring Keiser leg muscle strength and the protocols used for 1RM establishment varied across studies. Differences in the number of leg presses performed when establishing the 1RM maximum and amount of rest time between the 1RM and performing the muscle function test may affect strength and/or power results. Fatigue may result from 1RM protocols that require many leg presses or if adequate rest time between establishing the 1RM and performing the test is not offered. Those with fatigue from establishing the 1RM may have weaker leg strength or power compared to if they had performed fewer leg presses to establish the 1RM or had adequate rest time after establishing the 1RM. However, the 1RM protocol details were not provided for all studies using the 1RM but are needed to determine any effect of these protocol variations on the results. A standard protocol does not exist for establishing the 1RM and this methodological aspect should be considered in future studies of muscle function in older adults to determine if the protocol could cause fatigue and impact the results.

Leg strength from knee extension tests may be associated with physical performance, though not independent of confounding factors. Two studies showed that knee extension strength was related to physical performance. Biodex dynamometer leg strength was negatively correlated with usual walk gait speed over 7m ($r=-0.46$) and stair climb of 15 steps (ascent $r=-0.49$; descent $r=-0.51$)[147] and Kin-Com dynamometer leg strength was associated with impaired gait (<0.8m/s) in women (OR=2.40; 95% CI: 1.61–3.58) and men (OR=3.59; 95% CI: 2.63–4.89) independent of grip strength.[148] Very minimal population characteristics and information about model adjustments were provided in these studies. Certain confounders, such as age, musculoskeletal pain or comorbid conditions, may have accounted for the associations between leg strength and physical performance. Two studies assessed ankle strength as a measure of lower-extremity function to physical performance. Strength at the ankle was measured using a dynamometer and was associated with 400m walk time,[149] and stair climb time and gait speed, though not chair stands time.[150] Knee extension may be difficult to perform for older adults, especially those who are frail or who have osteoarthritis in the knee, due to pushing against a heavy external load. Future studies of leg extension press and physical performance should carefully assess the effect of frailty, pain and arthritis on estimates.

Leg power has traditionally been measured in the seated position using either leg press or leg extension equipment in studies of leg power and physical performance. Two studies have used the Keiser leg press machine.[144,151] while two have used the Nottingham leg extension power rig[149,152] to assess muscle function and examine these in relationship to physical performance. Lower Keiser power was associated with total SPPB score, 4m usual walk gait speed, 5 repeat chair stands and 6 minute walk distance,[144] and clinically meaningful changes after 16 weeks of exercise in SPPB (change of ≥1 point) and 4m usual walk gait speed (change of ≥0.1m/s).[151] Lower Nottingham leg power was related to slower 400m walk time[149] and slower 4m gait speed in men but not women.[152] These measures may not be ideal for those who have difficulty getting in and out of a chair or the seated position. Measures of muscle function that are body-weight bearing and do not require sitting may be more appropriate for these adults.

The strength and contraction velocity components of muscle power have been examined separately in relation to physical performance. The contraction velocity component of leg power from Keiser was a stronger predictor of performance physical performance compared to Keiser muscle strength.[145] This suggested that the velocity component of power may be a more sensitive predictor of physical performance compared to strength. Sex differences existed in the relationship between velocity and SPPB and 400m walk speed. This indicated that older men and women may use different strategies when asked to perform a particular task and that measures that include velocity may be better in studies of physical performance in men. Additionally, strength was not associated with SPPB or gait speed in women though was significantly associated with both in men.

No studies have examined the relationship between novel, body-weight bearing measures leg power (i.e., force plate jump testing) and physical performance measures in older adults.

Body-weight bearing movements may more closely approximate the ability to perform activities of daily living, such as climbing a flight of stairs, standing up from a chair, or walking. These measures may be more sensitive predictors of physical performance in older adults. Future studies should consider utilizing these novel measures of leg power to examine the relationship between muscle function and physical performance in older adults.

Table 11. Association of muscle function and physical performance in older adults

Authors	Total N or N per group; study	Demographics: age (mean± SD or range), sex, race, country	Other chronic disease/ lifestyle risk factors	Functional status	Muscle function measure/ Equipment	Physical performance measure	Findings/results
Marsh et al. 2006[149]	655 InCHIANTI	73.0 ± 6.1 53.3% women Greve in Chianti & Bagno a Ripoli (Chianti region of Tuscany, Italy)			Right ankle plantarflexion. isometric strength (kg; Penny and Giles. portable dynamometer) Right leg muscle power (Watts; Nottingham leg extensor power rig)	400m walk (20 laps on 20m course at. steady & constant pace)	Strength (linear model) R^2=52.3% *similar R^2 for quadratic& cubic models*. Power linear model R^2=55.6% quadratic model R^2=57.7% cubic model R^2=58.1% Strength & power linear model R^2=56.4% quadratic model R^2=58.7% cubic model R^2=59.1%
Misic et al. 2007[147]	55	69.3 ± 5.5 65% women		No structured exercise program in past 6 months	Strength (peak knee extension +. flexion torque; isokinetic Biodex dynamometer at 120°/s. velocity) Muscle quality (strength normalized by DXA. leg mineral free lean mass)	7m walk w/o obstacle 7m walk with obstacle Stair climb (ascent and descent 15 stairs at a normal pace, without using handrail if possible)	Strength correlated with ($p<0.05$): 7m walk r=–0.46 Stair ascent r=–0.49 Stair descent r=–0.51 Muscle quality. correlated with ($p<0.05$): 7m walk r=–0.57 Stair ascent r=–0.54 Stair descent r=–0.57 Muscle quality linear regression: 7m walk r^2=–0.32 Stair ascent r^2=–0.29 Stair descent r^2=–0.33 *No regression results for strength*
Makris et al. 2016[146]	Back pain group: 295	Back pain group: 76.8 ± 7.0	Back pain (yes/no; Self-Administered	Self-reported preclinical	Leg strength (greatest 1 RM value of either leg;	SPPB - 4m usual gait speed	<u>Back pain:</u> 4 m gait speed: - Leg strength NS

Table 11 Continued	No back pain group: 135 Boston RISE	65% women 83% white No back pain grpoup: 76.1 ± 7.1 73% women 82% white	Comorbidity Questionnaire; yes to "do you have the problem of back pain" &"do you receive treatment for it")	disability	Keiser A420 leg press machine) Leg velocity at peak power (Keiser A420 leg press machine)	- Balance - 5 repeat chair stands	- Leg velocity β=0.24* Balance: - Leg strength NS - Leg velocity NS 5 repeat chair stands: - Leg strength β=0.17* - Leg velocity NS <u>No back pain:</u> 4m gait speed: - Leg strength NS - Leg velocity β=0.17* Balance: - Leg strength β=0.07* - Leg velocity NS 5 repeat chair stands: - Leg strength β=0.09* - Leg velocity NS
Fragala et al. 2016[148]	Health ABC: 1,913	<u>Health ABC:</u> Women (52%): age=78.0 ± 2.8 Men (48%): age=78.4 ± 5.4			<u>Grip strength</u>: weak vs. not weak; kg; hand-held dynamometer or isometric GoodStrength chair <u>Leg extension strength:</u> weak vs. not weak; peak torque from isokinetic Kin-	<u>Gait speed:</u> <0.8 m/s vs. ≥ 0.8 m/s 4m usual gait speed	Grip strength & leg extension + correlated: Women r=0.44 Men r=0.40 <u>Grip strength</u> *Separate model:* Women: OR=1.99; 95% CI: 1.11–3.58 Men: OR=2.90; 95% CI: 1.62–5.18 *With leg strength included:* NS for women Men: OR=2.16; 95% CI: 1.18–3.96 <u>Leg strength:</u> *Separate model:* Women: OR=2.52; 95% CI: 1.71–3.71 Men: OR=3.92; 95% CI: 2.21–6.97 *With grip strength included:* Women: OR=2.40; 95% CI: 1.61–3.58

Table 11 Continued					Com dynamometer at 60°/second		Men: OR=3.21; 95% CI: 1.77–5.82
Fragala et al. 2016[148]	Age Gene/ Environment Susceptibility— Reykjavik Study (AGES- REYKJAVIK): 4,853	AGES- REYKJAVIK: Women (57%): age=76.4 ± 5.6 Men (43%): age=76.6 ± 5.4			Grip strength: weak vs. not weak; kg; hand-held dynamometer or isometric GoodStrength chair AGES- REYKJAVIK: highest of 3 maximal isometric leg extensions of dominant leg from GoodStrength. adjustable computerized dynamometer on fixed chair at 60°	Gait speed: <0.8 m/s vs. ≥ 0.8 m/s 6m. usual gait speed→ 4m gait speed	Grip strength & leg extension + correlated (all p<0.05): Women r=0.51 Men r=0.57 Grip strength *Separate model:* women: OR=3.92; 95% CI: 3.27–4.70 men: OR=4.43; 95% CI: 3.54–5.55 *With leg strength included:* women: OR=3.08; 95% CI: 2.55–3.73 men: OR=3.43; 95% CI: 2.68–4.32 Leg strength: *Separate model:* women: OR=4.52; 95% CI: 3.66–5.58 men: OR=5.77; 95% CI: 4.32–7.71 *With grip strength included:* women: OR=3.30; 95% CI: 2.64–4.12 men: OR=3.59; 95% CI: 2.63–4.89
Hicks et al. 2011[152]	Women: N=515 Men: N = 419 InCHIANTI	Women: 74.4 ± 6.8 Men: 73.3 ±. 6.4			Grip strength: kg; handheld dynamometer of right hand Knee extension strength: kg; isometric extension of right knee using handheld	4m usual gait speed: m/s; fastest of 2 trials; optoelectronic system recorded time between activation of 1st & 2nd cameras on course	*All results in Loess curves; no point estimates were provided* Gait speed ↓ in women with: Lower 3 yr knee extension strength Gait speed ↓ in men with: Lower 3 yr grip strength Lower 3 yr knee extension strength Lower 3 yr leg power Gait speed ↓ greater in men with:

Table 11 Continued					dynamometer <u>Leg power:</u> Watts; maximum of 8 trials on Nottingham leg extensor power rig Baseline & year 3 visits; Change = year 3–baseline	3 & 6 year visits; Change = year 6 –year 3	Large declines in grip strength Large declines in knee strength
Bean et al. 2010[151]	117 InVEST	75.2 ± 6.7 68% women		SPPB score 4-10 Ability to climb flight of stairs 16 week progressive resistance training (weighted vest or. free weights with arms & legs)	<u>Leg strength:</u> kg; 1RM on Keiser double leg press <u>Leg power:</u> Watts; 70% of 1RM on Keiser double leg press.	Clinically meaningful difference (CMD) from baseline to 16 week visits SPPB (CMD ≥ 1 point change) 4m gait speed (CMD ≥ 0.1 m/s change)	<u>Strength</u>: NS associated with SPPB or gait speed <u>Power:</u> ↑ odds of CMD in SPPB (OR; 95% CI) = 1.48; 1.09 - 2.02) ↑ odds of CMD in gait speed (OR; 95% CI) = 1.31; 1.01 - 1.70)
Puthoff et al. 2007[144]	30	77.3 ± 7.0		Self-reported mild to moderate functional limitations	<u>Leg strength:</u> kg; 1RM on Keiser double leg press <u>Leg power:</u> Watts; peak power, power at	SPPB 4m usual gait speed 5 repeat chair stands	<u>Strength:</u> SPPB total score β=0.32 Gait speed. β=0.03 Chair stands. β=-1.18 6min walk distance. β=12.84 <u>Peak power:</u> SPPB total score β=0.46 Gait speed. β=0.05

Table 11 Continued					40% 1RM & power 90% of 1RM on Keiser double leg press (also presses at 50%, 60%, 70% 80% of 1RM)	6 minute walk test	Chair stands. β=-1.75 6min walk distance. β=21.39 <u>Power at 40% 1RM:</u> SPPB total score NS Gait speed. β=0.05 Chair stands. β=-1.40 6min walk distance. β=19.68 <u>Power at 90% 1RM:</u> SPPB total score β=0.64 Gait speed. β=0.05 Chair stands. β=-2.21 6min walk distance. β=23.78
Sayers et al. 2005[145]	64 women 37 men	Women: 81.0 ± 0.5 Men: 80.4 ± 0.7			<u>Leg strength:</u> kg; 1RM on Keiser double leg press <u>Contraction velocity:</u> m/s; 1RM & 40% 1RM. on Keiser double leg press *Collected power, though did not relate power to SPPB or gait speed*	<u>SPPB:</u> score; 4m usual gait speed; balance; 5 repeat chair stands <u>Gait speed:</u> m/s; 400m self-paced walk; 4 laps on 100m course; m/s calculated to include non-completers	<u>Women:</u> <u>Leg strength:</u> NS associations with SPPB & gait speed <u>Contraction velocity (all p<0.05):</u> SPPB stdβ=0.29 Gait speed stdβ=0.49 <u>Men:</u> <u>Leg strength (all p<0.05):</u> SPPB stdβ=0.50 Gait speed stdβ=0.36 <u>Contraction velocity (all p<0.05):</u> SPPB. stdβ=0.32 Gait speed stdβ=0.42
Suzuki et al. 2001[150]	34	75.4 ± 5.1		≥ 2 limitations reported on. MOS-SF36 physical component section	<u>Strength:</u> plantarflexion (PF) & dorsiflexion (DF) of ankle muscles at 0°	<u>10 repeat chair stands:</u> seconds to the nearest 0.01s; without arms, if possible	<u>Strength:</u> Chair stands: PF & DF NS Stair climb: PF β= -4.9; DF β= -10.2 Usual gait: PF β=0.5; DF NS Max gait: PF β=0.5 ; DF β= 2.7 <u>Peak power:</u>

Table 11 Continued					Peak torque: highest value of 6 trials for each angle Power : (peak torque* angular velocity) for each angle Cybex II dynamometer; 5 submaximal repetitions as warmup; 6 PF & DF at 6 angles (30°, 60°, 90°, 120°, 180°, & 0°) with 1 minute rest in between trials; push down/pull toward as hard as possible for 5 seconds (strength); push foot away & pull toward at maximum velocity through full range of motion (ROM) at all 6 angles (torque/power)	Stair climb: seconds; time to ascend 8 stairs Usual gait speed: 10 meters at normal pace; speed recorded with. Ultra timer between 3m & 8m Maximal gait speed 10 meters at maximum pace; speed recorded with Ultra timer between 3m & 8m	Chair stands: PF β= -18.2; DF β= -61.7 Stair climb: PF β= -10.6; DF β= -30.3 Usual gait: PF β=0.7 ; DF β=2.3 Max gait: PF β=1.1; DF β=2.7 NS associations between PF & DF peak torque and chair stands, stair climb, usual gait & max gait

Table 12. Summary of associations between muscle strength and physical performance in older adults

Muscle function measure	Balance	Usual paced gait speed	Max pace gait speed	Long distance walk	5 chair stands speed	10 chair stands speed	SPPB	Stair climb
Grip strength								
Dynamometer		Fragala* Hicks† Visser 2000 Siglinsky Lauretani			Visser 2000 Siglinsky		Siglinsky	
Leg strength								
Dynamometer	Bean 2003 Ferrucci	Fragala* Hicks* Lauretani Bean 2003 Ferrucci		Marsh*	Bean 2003 Ferrucci		Bean 2003	Bean 2003
Keiser	Makris¥ Puthoff* Bean 2007	Puthoff* Sayers† Makris Bean 2007 Cuoco			Makris* Puthoff* Cuoco		Puthoff* Sayers† Bean 2007	Cuoco
Biodex		Misic* Thompson		Thompson	Thompson			Misic*
Kin-Com		Fragala*						Visser 2005
Jump		Hannam			Hannam			

*Significant for entire study population; †significant in men only; ¥ significant in those with no back pain only

Table 13. Summary of associations between muscle power and velocity and physical performance in older adults

Muscle function measure	Balance	Usual paced gait speed	Max pace gait speed	Long distance walk	5 chair stands speed	10 chair stands speed	SPPB	Stair climb
Leg power								
Nottingham	Bean 2003	Hicks† Bean 2003 Lauretani		Marsh*	Bean 2003		Bean 2003	Bean 2003
Keiser	Puthoff*	Cuoco Puthoff*			Cuoco Puthoff*		Puthoff*	Cuoco
Stair climb	Bean 2007	Bean 2007			Bean 2007		Bean 2007	
Jump		Siglinsky Hannam Thompson		Thompson	Siglinsky Hannam Thompson		Siglinsky	
Leg velocity								
Keiser (at peak power)	Makris	Makris*			Makris			
Keiser (at 1RM or 40% 1RM)		Sayers*					Sayers*	
Jump		Makris* Sayers*			Makris			
Muscle quality (Biodex strength/DXA fat-free lean mass)		Misic*						Misic*
Ankle strength (dynamometer)		Suzuki*	Suzuki*			Suzuki		Suzuki*
Ankle power (dynamometer)		Suzuki*	Suzuki*			Suzuki*		Suzuki*

*Significant for entire study population; †significant in men only; ¥ significant in those with no back pain only

7.0 Associations Between Muscle Function and Falls/Fall Injuries/Fractures in Older Adults

Declines in power and strength are related to frailty[153] and may be early markers of poor muscle function in older adults. Muscle weakness may lead to falls or fall injuries in older adults. Older adults have increased fall risk[153] and fallers have less overall power standardized by body weight compared to non-fallers.[154] However, less is known about the relationship between muscle weakness and fall injury. The epidemiology of non-fracture fall injuries has not been examined, though muscle function may be a risk factor for fall events, including non-fracture and fracture fall injuries.

A systematic review of 13 studies of muscle weakness and falls in older adults found that lower-extremity muscle weakness was associated with any fall (OR=1.76, 85% CI=1.31-2.37) and recurrent falls (OR=3.06, 85% CI=1.86-5.04).[155] Muscle function tests included grip strength (6 studies), chair stands (6 studies), knee extension dynamometer (3 studies), ankle dorsiflexion manual testing (3 studies), quadriceps strength with 1–repetition maximum (2 studies), shoulder, hip, or knee manual testing (2 studies) and/or upper extremity manual testing (1 study), though only 6 studies used methods with established reliability. Outcomes included any fall during the follow-up period, recurrent falls, or fall injury, mainly from self-report, though the timing, frequency, mode of assessment and follow-up varied across all studies.

Lower extremity weakness is a clinically important and statistically significant risk factor for falls, even when results were restricted to those reporting confounder-adjusted estimates. Upper extremity weakness may also be a risk factor, but only one study of upper extremity weakness provided adjusted results and upper-extremity weakness may not be independent of other risk factors. The relationship of various muscle function tests to each other and in relationship to health outcomes, such as physical performance or falls and fall injuries, within the same study of older adults with the same confounder-adjustments has not been studied since studies often do not multiple muscle function tests.

Older fallers had weaker lower-extremity muscle strength compared to older non-fallers. Crozara et al.[156] conducted a cross sectional study of 61 women in Brazil (N=18 young; N=21 older fallers; N=22 older non-fallers). The study evaluated motor response time and ability to develop joint torque at the knee and ankle in older women fallers and non-fallers. Peak knee extension torque, peak ankle dorsiflexion torque, and rates of torque development for knee and ankle strength tests were measured through a dynamometric Biodex assessment and simultaneous electromyography. Surface EMGs of the rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), gastrocnemius lateralis (GL) and tibialis anterior (TA) muscles were recorded. Older non-fallers had significantly higher peak knee extension torque (14%) compared to older fallers, though no significant differences existed between older fallers and non-fallers for peak ankle dorsiflexion torque and the rates of torque development. Both older groups had lower values for all measures compared to the younger group. Knee extension peak torque and motor time of the TA during ankle dorsiflexion accounted for approximately 28% of the variance in the number of falls in multiple linear regression analysis. History of falls and baseline functional level were not assessed but would be important confounders of both muscle function and falls. Additionally, the small sample of Brazilian women and lack of power calculations likely led to underpowered results. Examining the differences in muscle function between older fallers and non-fallers in a large population of older adults is essential.

Strength and power have been related to falls that were simulated in a clinic setting. Pijnappels et al.[157] conducted a cross-sectional study of healthy older men (n=10) and women (n=7) aged 75 years in Amsterdam who were 'fit' and free of orthopedic, neuromuscular, cardiac or visual problems, though criteria used to define 'fit' was not provided. Participants performed a series of static and dynamic maximum force generating capacity tests and data were collected for maximum, and rate of, ankle plantar flexion moment and knee extension moment via a dynamometer. Jump height was measured from the higher of two two-legged counter movement jumps as the vertical distance between the highest averaged hip position during jumping and averaged hip height during normal standing. Falls were generated in the clinic and assessed using visual detection. Participants wore a safety harness that moved along a track above the walkway and walked at a self-selected velocity over a 12 m walkway that contained hidden obstacles that would suddenly appear. Participants were aware that they could be tripped but did not know whether and where an obstacle would appear. Participants were classified as fallers based on visual detection of full body support by the harness (checked by video) in more than 50% of the tripping trials. Seven of the participants (all women) were fully supported by the safety harness in more than half of the tripping trials. Six of them fell in all trials; the other fell in three out of five trials. Non-fallers were never fully supported by the safety harness. Significant differences existed between fallers and non-fallers for the following strength and power variables, though magnitudes of differences were not presented: maximum plantar flexion moment (p=0.035), rate of development of plantar flexion moment (p=0.032), knee extension moment (p=0.011), rate of development of knee extension moment (p=0.016), maximum leg press push-off force (p=0.001), rate of development of leg press push-off force (non-significant/no p-value reported) and jump height (p=0.002). These findings suggest that women may be more likely to fall compared to men since women were the only fallers, though no sex-stratified analyses were completed. Falls were assessed in a simulated manner and may not accurately represent rate of falls during typical daily living activities. Additionally, nine participants were tested using a Cybex isokinetic dynamometer and eight using a custom-built dynamometer, and the methods for each were not well described, potentially biasing results if differential misclassification of the predictors from static and dynamic maximum force generating capacity tests occurred. The relationship between muscle function and fall risk in older adults will be better described when assessing falls that occur outside of a clinic setting and using consistent methods for measuring strength and power.

The relationship between leg power and falling has not been well-studied. Morris et al.[158] investigated if balance tests and fall history can predict falls in a cohort of 104 community-dwelling women aged 77.9 ± 6.5 years with vertebral fracture. In addition to the balance tests, leg extensor power was measured in a standardized manner, though the equipment and protocol used were not described. A 'faller' was defined as someone who fell once or more during the follow-up period. A 'previous faller' was someone who fell once or more in the preceding year, and a 'previous recurrent faller' (a subgroup of the 'previous faller' group) was someone who fell twice or more in the preceding year. Eighty-six (82.7%) women completed the study at 12 months and the non-completers were significantly older (4.7 years; 95% CI: 1.5–7.9) than completers, but there were no other significant differences between groups. Thirty-nine (45.3%) women had fallen in the first year. Leg extensor power (Watts) was not associated with being a faller in the first year (OR=1.00; p=0.82) in univariate analysis, therefore multivariate analysis was not conducted for leg extensor power. Women in this study were likely very different from all older women, leading to ungeneralizable results. Data collection methods for falls is not well described, though appear to be by self-report. Recall bias may have occurred, though only likely for the ‘previous faller’ group. Additional studies that utilize valid and reliable measures are needed to examine the relationship between power and fall risk.

Alternative methods for improving muscle power in older adults who are at risk of falling and may be unable to engage in regular exercise have been explored. Vibration training works by triggering muscle contractions at a higher rate than possible during normal exercise. By using mechanical stimulation to generate acceleration forces, the vibration causes muscles to subconsciously contract and lengthen and many more muscle groups are activated by the vibration than by voluntary movements performed during normal exercise. Corrie et al.[159] evaluated the influence of vertical vibration (VV), side-alternating vibration (SV), or Sham training in addition to usual care on musculoskeletal health in 61 men and women aged 80.2±6.5 years who were referred to an outpatient falls prevention service in a single- blind, randomized, controlled trial. Participants were requested to attend three vibration sessions per week for 12 weeks, with sessions increasing to six, 1 min bouts of vibration. Falls risk factors and neuromuscular tests were assessed at baseline and post-intervention. Leg power increased more in the VV group compared to the Sham group (23%, p=0.04), though changes in falls risk factors did not differ between the groups. It was unclear what methods were used to assess leg power, so reproducing this study is impossible. This intervention to increase muscle power and decrease fall and fall injury risk included a very specific population (those with a previous fracture) and are not generalizable to the overall aging population at risk of falls. The 12-week duration of the training may have been too short to observe falls, which may be why results were null for fall risk. Finally, vibration training may have potential benefits on power, though may not be feasible option for all adults because of the amount of time required for vibration training.

Leg strength may be related to fall risk in older adults with chronic conditions. Bird et al.[160] studied 69 independent community-dwelling men and women aged 73.5 ± 6.9 years with stable chronic disease including hypertension, cardiovascular disease, respiratory conditions and diabetes. Participants were recruited via local media (newspaper and radio) and local community clubs and had leg strength, physical activity levels and annual falls assessed at two time points over three years. Maximum isometric strength of the knee extensors and ankle dorsiflexors were measured using a spring based system that measured strength in kilograms.[161,162] This system uses a spring gauge attached to the subject's leg, though reproducibility and reliability of this measure for measuring knee and ankle strength has not been documented. This method requires specialized equipment that has cost and time disadvantages over other measures of strength. The highest value maintained for 2–3 seconds from the three trials was recorded. Average ankle and knee strength was determined by averaging the left and right knee and ankle values. Each participant in the baseline visit received a printed calendar, on which they reported details of any falls and associated injuries prospectively. The frequency and timing for when the fall calendars were filled out/sent in was not described. A fall was defined as “an unexpected event in which the participant came to a rest on the ground, floor or lower level”. A pre-paid envelope was provided for ease of return of the calendar. At the follow-up visit, participants recalled the number of falls experienced in the previous 12 months. Leg strength was not significantly different between visits, but the likelihood of falling was higher at the end of the study compared to the baseline visit (OR=1.93, 95% CI 0.94 to 3.94; p=0.07). Despite maintenance of leg strength, an increase in fall rates occurred. This indicates that mechanisms other than leg strength decline exist and should be explored.

Leg power has been shown to be related to incident fall risk. Chan et al.[105] examined the prospective relationship between leg extension power and incident falls in men (aged 73.7±5.9 years) over an average of 4.5±0.9 years. Maximum power was measured using the Nottingham power rig. Incident falls data were collected through triannual questionnaires that were mailed to participants, and these analyses include up to 17 questionnaires per participant. In fully-adjusted models, men in higher power quartiles (2, 3 and 4) had lower fall risk compared to men in the lowest power quartile (quartile 2 vs. 1 RR=0.88, 95% CI=0.81-0.97; quartile 3 vs. 1 RR=0.86; 95% CI=0.77-0.975; quartile 4 vs. 1 RR=0.82; 95% CI=0.73-0.92). While leg power was associated with self-reported falls risk, examining this relationship using claims data, such as Medicare, is important in order to reduce recall bias and show more robust associations.

Measures of physical performance have been used as a proxy for muscle function. The SPPB, a well-established measure of lower-extremity performance,[57] includes chair stand time, balance and gait speed. Chair stand time can be used as a surrogate measure of leg muscle function. Ward et al.[163] assessed risk factors and mechanisms of falls over 4 years in community-dwelling older adults (N=765; mean age 78.1±5.4 years) living in the Boston area. All participants were able to walk 20 feet without assistance from another person and excluded if moderately to severely cognitively impaired (MMSE<18). Older adults with slower chair stand times had higher risk of injurious fall compared to the fastest (HR [95% CI]: 1.96 [1.18–3.26], 1.65 [1.07–2.55], and 1.60 [1.03–2.48] for 1 vs. 2, 3, and 4, respectively). Though chair stand time was associated with increased fall risk, other measures of leg muscle function should be examined, including muscle strength and power.

Based on the review of the existing literature, an association between leg power/strength and fall risk in older adults exists when assessed cross-sectionally. Leg strength was associated with both increased falls and recurrent falls. Leg power was associated with increased fall risk in only one of the prospective studies,[105] likely due to the longer follow-up period for falls. Most prospective studies followed participants for 1 year. Extending the study timeframe to >1 year will allow incident fall risk into the oldest old ages to be observed. Cross-sectional studies show associations, though are unable to show causality. While low power, or decline in power, may lead to increased fall injury risk, the current literature of prospective studies and randomized control trials is lacking. It is important to note the studies typically include limited measures, and not multiple measures, of muscle function. Only one study in this review examined jump power as a predictor of falls and fall injuries, and most studies that incorporated novel measures of jumping utilized a surrogate measure of jump height.

8.0 Strengths and Limitations/Summary of Major Gaps in Literature

No studies to date have investigated the relationship between jump power and physical performance in older adults. Additionally, studies of muscle strength and falls/fall injuries have typically relied on strength measures of the lower extremities, though declines in muscle power may occur before strength decline.[55,56] It is important to identify modifiable risk factors that are treatable in order to maintain or prevent decline of muscle strength and power in late life. Novel measures of leg power have been shown to be reproducible in older adults and can be completed without pain or injury. Jump power assessed during a countermovement jump should be examined in relationship to physical performance since this measure may be an earlier predictor of physical performance because the ability to bear one's own body weight may more closely approximate physical function abilities related to daily living, like walking or standing up from a chair. Methods of leg power and strength assessments could be used to identify participants at the greatest risk of fall and injurious falls. However, because of the limited number of studies assessing leg muscle power and strength as predictors of falls and fall injuries, an overall conclusion regarding the relationship between leg power/strength and fall risk is unclear. Thus, further studies, including prospective cohorts and randomized control trials, need to be conducted in order to fully describe this association.

9.0 Jump Power, Leg Press Power, Leg Strength and Grip Strength Differentially Associated with Physical Performance: The Developmental Epidemiologic Cohort Study (DECOS)

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9.2 Abstract

Background. Weight-bearing jump tests that measure lower-extremity muscle power may be more strongly related to physical performance measures vs. non-weight-bearing leg press power, leg press strength and grip strength. We investigated these multiple muscle function measures related to various physical performance measures.

Materials/Methods. In the Developmental Epidemiologic Cohort Study (DECOS; N=68; age 78.5±5.5 years; 57% women; 7% minorities), muscle function measures included power in Watts/kg (functional, weight-bearing: jump; mechanical: Nottingham power rig; Keiser pneumatic leg press) and strength in kg/kg body weight (Keiser pneumatic leg press; hand-held dynamometry). Physical performance outcomes included 6m usual gait speed (m/s), usual-paced 400m walk time (seconds), and 5-repeated chair stands speed (stands/s).

Results. Women (N=31) had lower muscle function and slower gait speed compared to men (N=25), though similar 400m walk time and chair stands speed. In partial Pearson correlations adjusted for age, sex, race and height, muscle function measures were moderately to strongly correlated with each other (all $p<0.05$), though the strength of individual correlations varied. In multiple regression analyses, each muscle function measure was statistically associated with all physical performance outcomes in models adjusted for age, sex, race, height, self-reported diabetes, self-reported peripheral vascular disease and self-reported pain in legs/feet (all $p<0.05$). Jump power (β=0.75) and gait speed (β=0.71) had higher magnitudes of association with faster gait speed than lower-extremity power and strength measures (β range: 0.32 to 0.58). Jump power (β=0.56) had a lower magnitude of association with faster 400m walk time vs. Keiser power (β=0.61), and a higher magnitude of association vs. Nottingham power, Keiser strength and grip strength (β (range: 0.41 to 0.47). Jump power (β=0.38) had a lower magnitude of

association with chair stands speed than any other power or strength measures (β range: 0.50 to 0.65).

Conclusions. Jump power/kg and grip strength had stronger magnitudes of association with faster gait speed, a standard measure of physical function and vital sign related to risk of disability and mortality in older adults than lower-extremity muscle function measures. Both jump power/kg and Keiser power/kg had stronger magnitudes of associations with longer 400m walk time than the other muscle function measures. Jump power/kg had a lower magnitude of association with chair stands speed than the other muscle function measure. Importantly, choice of muscle function measures should carefully reflect the study focus and methodologic considerations, including population.

Key words. Epidemiology, muscle, countermovement, power, physical function

9.3 Introduction

Both muscle power (force*velocity)[31,32] and strength have been extensively used as measures of muscle mechanical function in aging studies. However, inconsistent relationships of lower-extremity muscle power and strength have been found with usual gait speed, 400m walk time, 6 minute walking distance, chair stand speed, the Short Physical Performance Battery (SPPB) score and stair climb time.[61,76,144,148,149,152,153,164-169] These inconsistent findings may be due to the different intrinsic properties of power vs. strength and the variability in protocols to test power and strength.[170] Most studies have measured lower-extremity muscle function using dynamic or isometric movements in the seated position with power rigs[76,149,152,153] or leg press,[144,164] and static upper-extremity muscle function using grip strength.[61,76,148,152]

Nevertheless, functional, weight-bearing tests assessing muscle power may be more strongly related to the ability to perform objective measures of physical performance that are also weight-bearing (e.g., walking or rising from a chair), vs. non-weight-bearing tests. The few studies relating weight-bearing tests (i.e. jump tests) to physical performance are limited since they have not included and/or compared other muscle mechanical function tests.[61,167,168,171] Identifying if certain muscle function measures are more strongly related to physical performance vs. others may help when selecting the most appropriate tests for examining these relationships in older adults.

We examined associations of multiple muscle function measures, including lower-extremity muscle mechanical power and strength, and upper-extremity muscle strength with physical performance (400m walk time, 6m usual gait speed and 5-repeated chair stands speed) in older adults. We hypothesized that weight-bearing power would be more strongly related to physical performance than other non-weight-bearing lower-extremity muscle function measures and upper-extremity grip strength.

9.4 Materials and Methods

Participants. The Developmental Epidemiologic Cohort Study (DECOS) was conducted at the University of Pittsburgh in community-dwelling older adults (age 70+ years) recruited using the Pittsburgh Claude D. Pepper Older Americans Independence Center Research Registry.[172] Exclusion criteria included any self-reported health contraindication to physical testing and the inability to perform basic mobility tasks (e.g. severe pain, aching, or stiffness while walking). A total of 68 participants enrolled in the study. Participants had two clinic visits scheduled 8 to 14 days apart, and 64 completed both visits. Of those 64 participants, 87.5% (N=56) completed all muscle function measures (jump power, Nottingham power, Keiser power and strength, and grip strength) and the physical performance measures (6m usual gait, 400m usual walk, and chair stands). The University of Pittsburgh Institutional Review Board approved this study and all participants provided written informed consent prior to participation. Participants were excluded if they had a Modified Mini-Mental State Exam[173] score of <80, which was administered at the beginning of the first visit.

9.4.1 Muscle Function Measures

9.4.1.1 Jump power/kg

Advanced Mechanical Technology Inc. (AMTI) AccuPower force plates (Netforce Acquisition Software Version 3.05.01 with Accugait RS-232 setting and Biosoft Analysis software version 2.3.0) collected force signals from jump trials at a 1000 Hz sampling rate. The jump test protocol has been previously described.[11] Briefly, three countermovement jumps (4-5 maximum if ≥1/3 had data quality or technical problems) on the force plate were performed. Jump instructions were to jump as quickly and as high as possible without pausing between bending the knees and jumping, land smoothly, and then stand up straight and remain still. Participants were not instructed on use of arms during jumps for a more free-living movement. Pain was reported after jump tests; no participants stopped further testing due to pain. No serious adverse safety events occurred.

Muscle power from the trial with the highest jump height was selected for analysis. All participants had at least ≥1 trial without any technical and data processing exclusions. The analytic variable from the selected trial was jump peak power standardized by body weight (Watts/kg body weight).

9.4.1.2 Leg press power and strength

The same leg tested during the Nottingham power assessment was tested during Keiser strength and power assessments. Single leg press power was measured using the Nottingham power rig (Nottingham University, Nottingham, England).[46]. Participants were instructed to push the pedal as hard and as fast as possible through a full range of motion. Testing was performed until power plateaued, or participants completed 5-10 trials to obtain peak power (Watts). The analytic variable from the selected trial was Nottingham peak power standardized by body weight (Watts/kg body weight).

Keiser pneumatic resistance machines also measured single leg press power, as well as leg press strength. Participants were seated with the leg at a 90° angle and instructed to press their leg as fast as possible through a full range of motion. The resistance used for the power assessment was calculated as following. First, the 1 Repetition Maximum (1-RM) was established with a starting resistance of 40 pounds of force (the lowest setting). The Rating of Perceived Exertion (RPE; scale: 6 = "no exertion at all" to 20 = "maximal exertion") was reported with rest for 30 seconds between each repetition for which the RPE ≥ 15 "hard/heavy". Resistance was gradually increased until the participant reported an RPE=18 (between "very hard" and "extremely hard"). 1-RM testing ended when participants reported that they could not continue with higher resistance. After approximately 30 minutes of no physical activity following the 1-RM assessment, power testing was completed. Participants completed 2 trials each for 40%, 50%, 60%, and 70% 1RM with 30 seconds of rest between each trial at the same level of resistance and 1 minute of rest between each increase in resistance. The analytic variables included: 1) peak power standardized by body weight (Watts/kg body weight) which was obtained during 70% 1RM for all participants and 2) 1RM strength standardized by body weight (kg/kg body weight).

9.4.1.3 Grip strength/kg

Grip strength was measured using Jamar dynamometers (Sammons Preston Rolyan, Bolingbrook, IL, USA)[174] for two trials of both hands. Maximum grip strength was normalized to body weight (kg/kg body weight).

9.4.2 Lower-extremity Physical Performance Measures

9.4.2.1 6m usual gait speed

Time to walk 6m at the participant's usual pace was recorded.[175] Gait speed was calculated from the fastest time of two trials (m/s).

9.4.2.2 Usual-paced 400m walk time

Time to walk 400m (10 laps on 20m course) at the participant's usual pace without overexertion[172] was recorded at the second visit. Participants could rest for ≤60 seconds at any time during testing (without leaning on any surface or sitting down).

9.4.2.3 Chair stands speed

Ability to rise once from a standard chair was recorded. Time to complete 5-repeated chair stands without using arms was recorded for all study participants. Chair stands speed was calculated as five stands divided by the time to complete the test (stands/second).

9.4.3 Covariates

Information on age (years), sex (women/men), race (white/other), smoking status (current/former/never),[176] and education (college or higher/ less than college) was obtained from self-administered questionnaires. Body mass index (BMI) was calculated from weight (balance beam or digital scales) and height (Harpenden stadiometers; Dyved UK). Multimorbidity included self-reported health from the 12-Item Short-Form Health Survey (SF-12),[177] self-reported difficulty walking ¼ mile (yes/no), self-reported very easy to walk ¼ mile (yes/no), self-reported diabetes (yes/no), and self-reported peripheral vascular disease (PVD; yes/no). Sensory nerve function was assessed using standard 10-g and light touch 1.4-g monofilaments at the dorsum of the great toe by trained examiners after warming the participant's right foot (unless contraindicated, in which case testing was performed on the left side) to 30°C.[178] Insensitivity (yes/no) was defined as the inability to detect at least 3 of 4 touches (combined as 1 variable in analyses). Peripheral neuropathy symptoms included self-reported pain (yes/no) or numbness (yes/no) in the feet or legs in the past 12 months.

9.4.4 Statistical Analyses

Descriptive statistics included two-sided t-tests and Chi-square tests to compare baseline characteristics between women and men. Muscle function measures were normalized by body weight to account for total body mass. Partial Pearson correlations were calculated between jump power/kg, Nottingham power/kg, Keiser power/kg, Keiser strength/kg, grip strength/kg, 400m walk time, gait speed and chair stands speed, and were adjusted for age, sex, race and height. BMI was not entered as the outcomes were adjusted for weight. Correlations were classified as weak ($r < 0.4$), moderate ($0.4 \leq r \leq 0.6$), or strong ($r > 0.6$) (Evans 1996). Separate stepwise multivariable-adjusted linear regression models were built to evaluate the associations per standard deviation (SD) of jump power/kg, Nottingham power/kg, Keiser power/kg, Keiser strength/kg and grip strength/kg with physical performance. Covariates with $p<0.10$ in any model were retained in all final models. As a final step, muscle function measure*sex interaction was entered into the fully adjusted models and retained if $p<0.05$. Standardized β coefficients and 95% confidence intervals were reported to compare results across all models. We also calculated percent difference as $[(\beta1-\beta2)/\beta2]*100$, where β2=jump power and β1=other power/strength measure, with negative values indicating lower β for power/strength measure vs. jump power. As a sensitivity analysis, we replaced the normalized muscle function variable with absolute muscle function variable and adjusted for body weight; any attenuation in β coefficients or change in significance level was assessed. Analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC).

9.5 Results

Compared to men, women had 31% lower jump power, 42% lower Nottingham power, 31% lower Keiser power, 26% lower Keiser strength and 33% lower grip strength (Table 14; all $p<0.05$). Women also had 9% slower usual gait speed compared to men ($p<0.05$), though similar usual-paced 400m walk time and chair stands speed (Table 14). Women were more likely to report pain and numbness in legs/feet vs. men (Table 1; all $p<0.05$).

In partial Pearson correlations adjusted for age, sex, race and height, muscle function measures were correlated with each other (Table 15; all $p<0.05$), though the strength of individual correlations varied. For performance measures correlations, jump power/kg was moderately correlated with 400m walk time ($r=0.54$; $p<0.05$) but weakly correlated with gait speed and chair stands speed ($r=0.31$ and 0.27, respectively; all $p<0.05$). Nottingham power/kg and Keiser power/kg were moderately correlated with all physical performance measures (range: $r=0.40$ to 0.55; all $p<0.05$). Keiser leg strength was moderately correlated with 400m walk time and chair stands speed (both $r=0.49$; all $p<0.05$), but weakly correlated with gait speed ($r=0.32$; $p<0.05$). Grip strength was weakly correlated with all physical performance measures (range r: 0.29 to 0.35; all $p<0.05$).

In multiple regression analyses, each muscle function measure was related to all physical performance outcomes in models adjusted for age, sex, race, height, self-reported diabetes, self-reported PVD and self-reported pain in legs/feet (Figure 6; all $p<0.05$). Muscle function became more strongly associated with physical performance outcomes with the addition of diabetes, PVD and pain symptoms in the legs/feet. Jump power ($\beta=0.75$; additionally adjusted for jump power/kg*sex interaction) had a higher magnitude of association with faster usual gait speed than any other power or strength measure (Figure 7): 32% higher than Nottingham power/kg ($\beta=0.51$), 23% higher than Keiser power/kg ($\beta=0.58$), 57% higher than Keiser strength/kg ($\beta=0.32$), and 5% higher than grip strength/kg ($\beta=0.71$; additionally adjusted for grip strength/kg*sex interaction. Jump power ($\beta=0.56$) had a 9% lower magnitude of association with longer 400m walk time than Keiser power ($\beta=0.61$), though was 18% higher than Nottingham power ($\beta=0.46$), 16% higher than Keiser strength ($\beta=0.47$) and 27% higher than grip strength ($\beta=0.41$) (Figure 7). Jump power ($\beta=0.38$) had a lower magnitude of association with faster chair stands speed than any other power or strength measure: 32% lower than Nottingham power ($\beta=0.50$), 71% lower than Keiser power ($\beta=0.65$), 32% lower than Keiser strength ($\beta=0.50$) and

37% lower than grip strength/kg. In sensitivity analyses, β coefficients were not attenuated when replacing the normalized muscle function variable with the absolute variable and adjusting for body weight (data not shown).

9.6 Discussion

The magnitude of association of jump power and grip strength with faster gait speed was approximately 1.5 to 2-fold higher than each of the traditional lower-extremity measures of muscle function, even after adjusting for potentially confounding factors. Gait speed is commonly considered a standard measure of physical function and vital sign related to higher risk of disability[77,179] and mortality[77,180] in large epidemiologic studies of older adults. The magnitude of associations of both jump power and Keiser power with longer 400m walk time was higher than other muscle function tests, though each measure was statistically associated with each physical performance test. However, the magnitude of association of jump power with faster chair stands speed was lower than any other power and strength measure. Diabetes, PVD and pain symptoms in the legs/feet may significantly impact both muscle function and physical performance in older adults, as muscle function became more strongly associated with physical performance outcomes with the addition of these covariates. To our knowledge, this is the first study in older adults to compare magnitudes of association with multiple physical performance measures for weight-bearing and non-weight-bearing lower-extremity muscle mechanical function, as well as upper-extremity grip strength. Weight-bearing jump power methods and grip strength may be more strongly related to 6m usual gait speed, a standard measure of muscle function that has been related to functional outcomes of sarcopenia, frailty and disability[181] in older adults. However, other methods, particularly the Keiser leg power assessment, may be more similar or more strongly related to 400m walk time or chair stands speed than weight-bearing power measures. All DECOS participants had maximum power at 70% of the 1RM. Power assessed with Keiser leg press at 70% 1RM may be more similar to power from task-based power measures (e.g. jump tests), whereas Keiser leg press at lower percentages of the 1RM (e.g. 40%) may be more similar to power from other seated methods (e.g. Nottingham leg press). The muscle function measures selected should consider not only the study outcomes, but also methodologic considerations including functional ability of the population.

In contrast with unilateral, non-weight-bearing leg press measures that include concentric but not eccentric muscle action, the jump test is a bilateral weight-bearing muscle function measure that may more closely replicate the weight-bearing conditions of physical performance measures. Jumping includes both eccentric and concentric muscle action, as well as velocity of movement and other neuromuscular factors (e.g., postural control)[182] that are also required to complete physical performance measures. In previous studies of associations between both lower-extremity muscle power or strength and physical performance[76,144,152,153,164,167,168,171] most lower-extremity power measures were non-weight-bearing tests in the seated position.[76,144,152,153,164] In previous studies that included weight-bearing muscle function tests, associations with physical performance were lower than in our study,[167,168,171] possibly since we included healthier older adults who were able to complete all muscle function and physical performance measures. Hannam et al.[168] (N=463; 71-87 years; age 77±4 years) included only women and adjusted standardized estimates were stronger for jump power (gait speed β=0.44; chair time β =0.42) than lower-extremity strength from jump tests (gait speed β=0.13; chair stands time β=0.23). Winger et al[171] (N=1,242, 71-101 years, age 77±4 years) found stronger associations for jump power (gait speed β=0.42; 400m walk time β=0.47; chair stands speed β=0.43) than lower-extremity strength from jump tests (gait speed β=0.18; 400m walk time β=0.24; chair stands speed β=0.23) in older men. None of these past studies included non-weight-bearing muscle function tests; therefore, they could not compare lower-extremity jump power and strength to leg press power or leg press strength or determine whether specific muscle function measures are more related to certain performance outcomes than others. Our results suggest that weight-bearing jump test measures and grip strength may be more robust predictors of gait speed compared to seated power and strength measures and therefore should be considered in studies of muscle function and physical performance in aging populations, especially those with difficulty performing seated tests.

Dynamic lower-extremity muscle mechanical function tests muscle groups involved in weight-bearing tasks, whereas upper-extremity grip strength is a static muscle action measure that does not include weight-bearing muscle groups. We showed that all lower-extremity muscle function measures were more strongly associated with the 400m walk test, an assessment of mobility that requires endurance, fatigue resistance and aerobic capacity,[183] than upper-extremity grip strength. However, associations with gait speed and chair stands speed were similar for lower-extremity power and strength and upper-extremity grip strength. Only one past study compared associations of lower-extremity power, lower-extremity strength and upper-extremity strength with physical performance. Winger et al.[171] found that jump power in older men had a stronger relationships with 400m walk time, gait speed and chair stands speed (β range: 0.42 to β=0.47) than both lower-extremity strength from jump tests (β range 0.18 to 0.24) and grip strength (β range: 0.23 to 0.28), and relationships of lower-extremity strength from jump tests and grip with physical performance were similar. Compared to our study population of men (age=79.8±5.0 years; 400m walk time=378.3±62.9 seconds; gait speed=1.2±0.2 m/s; chair stands speed=0.4±0.1 stands/second), this past study included older men (age=84±4 years) with slightly worse physical performance (400m walk=369±85 seconds; gait speed=1.18±0.22 m/s; chair stands speed 0.42±0.14 stands/second). This suggests that lower-extremity weight-bearing tests may be more appropriate than upper-extremity non-weight bearing tests in older, less functional populations of older adults than well-functioning older adults. Jump power may be able to differentiate within poor functioning individuals, likely due to values of jump power with wider ranges in the oldest adults and with functional limitation.[11] Furthermore, lower-extremity muscle mechanical function measures, especially weight-bearing and non-weight bearing power, may be more direct measures of the muscle groups needed to complete the 400m walk test. However, grip strength may be a proxy measure of lower-extremity muscle function.

Both the weight-bearing and traditional seated lower-extremity muscle power and strength measures in our study have varied methodological considerations. The Nottingham power rig test is time-consuming as the protocol requires 5-10 total leg presses per leg. The operator effort is also substantial since the seat and heavy flywheel which are low to the ground must be manually adjusted prior to each test. The Keiser pneumatic resistance machine protocol used in this study had high participant burden as well since it requires the 1-RM to be established first, and then up to 9 total leg extensions for the power assessment and may result in participant fatigue since total test time is 1 hour minimum. Frail older adults or those with chronic health conditions, may have difficulty sitting in the required positions for both Nottingham and Keiser testing and/or pushing against the leg press through the full range of motion. Therefore, these seated measures lack feasibility for a large epidemiologic study of older adults who must be able to complete multiple study measures. The data processing of jump test trials is time intensive due to custom-designed algorithms.[11] Jump testing may be more appropriate in studies of older adults who may not be able to perform the seated tests. However, those with poor balance may not be able to perform the jump test safely. Future studies may consider modifications to the jump test methodology to reduce exclusions while still ensuring participant safety, such as use of a harness. However, these factors regarding burden of testing and data processing must be considered in studies of older adults.

Our study had several strengths and limitation. The study evaluated multiple power, strength and physical performance tests, though the cross-sectional design did not allow examination of muscle function as predictors of future physical performance decline. Magnitudes of association were compared with each outcome, however tests if standardized estimates of muscle function measures were statistically different were not completed and associations for women and men separately were not examined due to the small sample size. The community-dwelling, largely white population who were able to attend a clinic exam limits generalizability, however a strength is that our cohort included men and women over aged 70 years, with half of the sample aged 80 years and older. Finally, other methods for measuring lower-extremity muscle function, such as the stair climb and knee extension strength tests, were not included.

In conclusion, functional, task-based power methods (e.g., jump tests) and grip strength may be more strongly related to faster usual gait speed, a standard measure of physical function related to both mobility-related disability and mortality in older adults, compared to traditional leg press power and strength in older adults. However, jump power had a lower magnitude of association with faster chair stands speed and Keiser power/kg had stronger magnitudes of associations with longer 400m walk time vs. other muscle function measures. Therefore, the choice of muscle function measure should carefully reflect the study focus and methodologic considerations, including population.

9.7 Funding

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9.8 Tables and Figures

Table 14. Baseline characteristics by muscle function and physical performance completion, Developmental Epidemiologic Cohort Study, N=56

	Total (N=56)	Women (N=31)	Men (N=25)
Demographics			
Age, years	79.3 ± 5.9	79.8 ± 5.0	78.7 ± 6.6
Women	55.4 (31)		
White race	92.9 (52)	87.1 (27)	100.0 (25)
Anthropometry			
Height, cm			
Weight, kg			
Body Mass Index, kg/m^2	26.9 ± 4.1	27.0 ± 4.9	26.8 ± 3.0
Lifestyle characteristics			
Education ≥ college	83.9 (47)	83.9 (26)	84.0 (21)
Former smoker	51.8 (29)	54.8 (17)	48.0 (12)
Comorbidity			
Self-report excellent health	33.9 (19)	35.5 (11)	32.0 (8)
Self-report no difficulty walking ¼ mile	92.9 (52)	90.3 (28)	96.0 (24)
Self-report very easy to walk ¼ mile	65.4 (34)	60.7 (17)	70.8 (17)
Self-reported diabetes	3.6 (2)	3.2 (1)	4.0 (1)
Self-reported PVD	5.4 (3)	6.5 (2)	4.0 (1)
Sensory nerve function			
Monofilament sensitivity			
Light monofilament insensitivity	41.1 (23)	41.9 (13)	40.0 (10)
Standard monofilament insensitivity	17.9 (10)	16.1 (5)	20.0 (5)
Pain in legs/feet	17.9 (10)	29.0 (9)*	4.0 (1)
Numbness in legs/feet	32.1 (18)	45.2 (14)	16.0 (4)
Muscle function			
Jump power, W/kg body wt	20.4 ± 6.7	17.9 ± 5.9*	23.6 ± 6.3
Nottingham power, W/kg body wt	1.4 ± 0.5	1.2 ± 0.4*	1.7 ± 0.6
Keiser power, W/kg body wt	5.1 ± 1.8	4.5 ± 1.3*	5.9 ± 2.0
Keiser strength, kg/kg body wt	4.8 ± 1.5	4.3 ± 1.2*	5.4 ± 1.7
Grip strength, kg/kg body wt	0.3 ± 0.1	0.3 ± 0.1*	0.4 ± 0.1
Physical performance			
6m usual gait speed, m/s	1.2 ± 0.2	1.1 ± 0.1*	1.2 ± 0.2
Usual-paced 400m walk time, seconds	377.4 ± 59.9	376.7 ± 58.5	378.3 ± 62.9
Chair stands speed, stands/second	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1

*p<0.05 for women vs. men; values in table are mean ± standard deviation or % (n)

Table 15. Correlations between jump measures, grip strength and physical performance, Developmental Epidemiologic Cohort Study, N=56

	Nottingham power, W/kg body wt	Keiser power, W/kg body wt	Keiser strength, kg/kg body wt	Grip strength, kg/kg body wt	6m usual gait speed, m/s	Usual-paced 400m walk time, seconds	Chair stands speed, stands/s
Jump power, W/kg body wt	**0.50***	**0.63***	**0.50***	**0.43***	0.31*	**-0.54***	0.27
Nottingham power, W/kg body wt		**0.58***	0.39*	0.34*	**0.42***	**-0.41***	**0.40***
Keiser power, W/kg body wt			**0.72***	**0.52***	**0.46***	**-0.50***	**0.55***
Keiser strength, kg/kg body wt				**0.50***	0.32*	**-0.49***	**0.49***
Grip strength, kg/kg body wt					0.29*	-0.35*	0.35*

*p<0.05 for correlations adjusted for age, sex, race and height; r<0.4 weak, **0.4≤r≤0.6 moderate, r>0.6 strong**; W=Watts, wt=weight

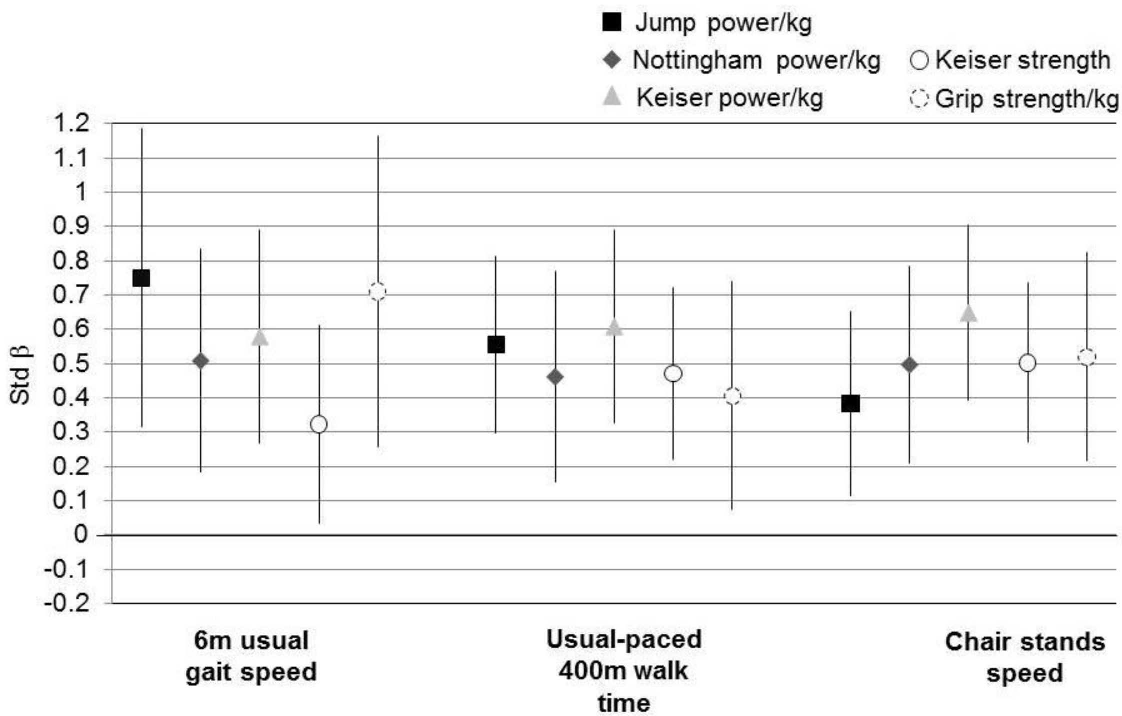

Figure 6. Associations (standardized β and 95% confidence intervals) of muscle power and strength measures with physical performance*, Developmental Epidemiologic Cohort Study, N=56

*all $p<0.05$; models for jump power/kg with 6m usual gait speed and grip strength/kg with 6m usual gait speed include the measure*sex interaction term; all models adjusted for age, sex, race, height, self-reported diabetes, self-reported PVD and self-reported pain in legs/feet

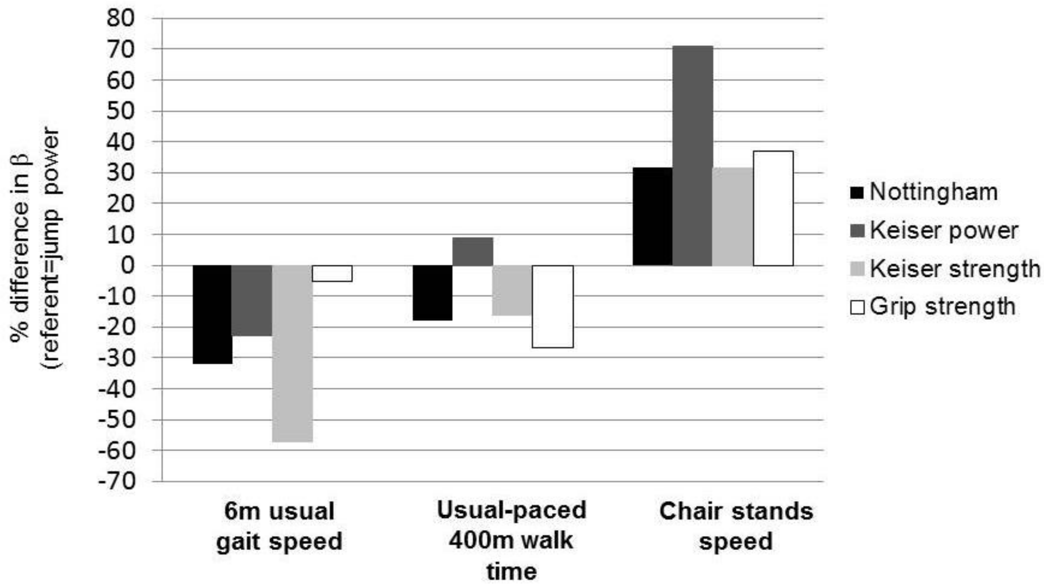

Figure 7. Percent difference in βs between continuous jump power and other power and strength variables*, Developmental Epidemiologic Cohort Study, N=56

*% difference calculated as $[(\beta1-\beta2)/\beta2]*100$, where $\beta2$=jump power and $\beta1$=other power/strength measure; negative values indicate lower beta for power/strength measure vs. jump power (e.g., for 6m usual gait speed, Nottingham power β is 32% lower vs. jump power β)

10.0 Associations Between Novel Jump Test Measures, Grip Strength and Physical Performance: The Osteoporotic Fractures in Men (MROS)

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10.2 Abstract

Background/Aims. Weight-bearing jump tests measure lower-extremity muscle power, velocity and force, and may be more strongly related to physical performance than grip strength. However, these relationships are not well-described in older adults.

Methods. Participants were 1,242 older men (mean age=84±4 years) in the Osteoporotic Fractures in Men (MrOS) study. Jump peak power (Watts/kg body weight), force (Newton/kg body weight) at peak power, and velocity (m/s) at peak power were measured by jump tests on a force plate. Grip strength (kg/kg body weight) was assessed by hand-held dynamometry. Physical performance included 400m walk time (seconds), 6m usual gait speed (m/s), and 5-repeated chair stands speed (#/s).

Results. In adjusted Pearson correlations, power/kg and velocity were moderately correlated with all performance measures (range: $r=0.41$-0.51; all $p<0.001$), while correlations for force/kg and grip strength/kg were weaker (range: $r=0.20$-0.33; all $p<0.001$). Grip strength/kg was also moderately correlated with power/kg ($r=0.44$; $p<0.001$) but not velocity or force/kg. In adjusted linear regression with standardized βs, 1 SD lower power/kg was associated with worse: 400m walk time ($\beta=0.47$), gait speed ($\beta=0.42$), and chair stands speed ($\beta=0.43$) (all $p<0.05$). Associations with velocity were similar (400m walk time: $\beta=0.42$; gait speed: $\beta=0.38$; chair

stands speed: β=0.37; all p<0.05). Force/kg and grip strength/kg were more weakly associated with performance (range: β=0.18-0.28; all p<0.05).

Discussion/Conclusions. Jump power and velocity were more strongly associated with physical performance than jump force or grip strength. This suggests lower-extremity power and velocity may be more strongly related to physical performance than lower-extremity force or upper-extremity strength in older men. Functional, task-based power and velocity may more closely replicate weight-bearing conditions of physical performance measures than strength alone.

Key words. Epidemiology, muscle, countermovement, power, physical function

10.3 Introduction

Weight-bearing power tests (i.e. jump tests) may more closely approximate the ability of older adults to perform activities of daily living (e.g. walking, chair rising) than non-weight-bearing tests. Jump power is a bilateral, weight-bearing measure that incorporates eccentric and concentric muscle action, and also includes neuromuscular factors (e.g., balance).[182,184] Conversely, the leg power tests in past studies were unilateral, non-weight-bearing tests with concentric muscle action only in the seated position.[76,144,152,153,164] However, power has often been assessed in a seated position with power rigs[76,149,152,153] or leg press.[144,164] Past studies utilizing jump tests are limited since they have traditionally reported power only for jumps with a flight phase (i.e., participant able to lift the feet off the ground).[12,31,52,53,61,66,76,167-169,185,186] The novel force plate jump testing methodology we developed[11] also calculates power from jumps without a flight phase.

While both muscle power, the ability of a muscle to exert force quickly,[31,32] and strength are lower at older ages compared to younger ages, larger magnitudes of age-related decline have been described for power than for strength.[11,13-16,66] This suggests that power rather than strength may be an earlier indicator of age-related muscle function loss. Inconsistent relationships for both muscle power and strength with standard physical performance tests (i.e., usual gait speed, 400m walk time, 6 minute walking distance, chair stand speed, the Short Physical Performance Battery score, stair climb time) have been found,[61,76,144,149,152,153,164,165,167-169,185] possibly due to variability in power test protocols,[187] particularly lack of task-based muscle function assessments such as the jump test.

The extent to which muscle power and its components (force and velocity), and strength may be differentially associated with multiple physical performance measures is unclear, though critical for selecting the most appropriate muscle function tests to predict late-life functional decline and disability. We examined associations of our novel jump test measures (jump peak power, and velocity and force at peak power) and grip strength with physical performance (400m walk time, 6m usual gait speed and 5-repeated chair stands speed) in older men. We hypothesized that jump peak power and velocity would be more strongly related to physical performance than jump force and grip strength.

10.4 Methods

10.4.1 Participants

The Osteoporotic Fractures in Men (MrOS) Study (http://mrosdata.sfcc-cpmc.net) is a multicenter, longitudinal cohort study designed to evaluate healthy aging, with a focus on risk factors for osteoporosis and fractures. Baseline visits occurred between March 2000 and April 2002 at six U.S. sites (N=5,994; aged 73.7±5.9 years).[175,188] Initial eligibility criteria included age ≥65 years; ability to walk without assistance or walking aid; ability to provide self-reported data and informed consent; residence near a clinical site; and absence of bilateral hip replacement or any severe disease/condition that would result in imminent death. Of 5,994 at baseline, 3,570 did not have a follow-up visit in 2014-2016 (2,822 deaths, 386 prior terminations, 362 refusals), and 583 completed questionnaires only and did not have an in-person clinic visit. The remaining 1,841 who completed a 2014-2016 clinic visit were included in current analyses.

10.4.2 Jump Test

Advanced Mechanical Technology Inc. (AMTI) AccuPower force plates (Netforce Acquisition Software Version 3.05.01) collected force signals from jump trials at a 1000 Hz sampling rate. As previously described,[11] 24.8% (N=456/1,841) participants were initially excluded from attempting jump tests for reasons related to health (unable to walk or stand with/without an aid, self-reported severe pain, or selected surgeries in the past 6 months: spinal or lower-extremity surgery, or knee or hip replacement) or other safety/logistical reasons (refusal, examiner deemed test unsafe, could not perform without orthotics, shortened clinic visit). An additional 6.4% (N=117/1,841) who attempted but did not complete jump tests were unable or refused practice tests mostly for balance-related issues, had severe pain during practice tests, or technical issues.[11]

Three calf rises were completed as a warm-up before a practice jump. Three countermovement jumps (4-5 maximum if ≥1/3 jumps had data quality or technical problems) were performed on the force plate. Jump instructions were to jump as quickly and as high as possible without pausing between bending the knees and jumping, land smoothly, stand up straight, and remain still. Participants were not instructed on use of arms during jumps for a more free-living movement. Pain intensity (scale: 0-10; "0"=none, "10"=severe pain) and pain location were reported after jump tests; 4.6% (N=58/1,268) with jump tests reported post-jump pain with only 2 participants stopping further testing due to pain. No serious adverse safety events occurred.

The University of Pittsburgh Reading Center and Southern Denmark University Processing Center (SDUPC) reviewed force plate data. SDUPC batch analyzed valid trials with custom-designed software.[11,12,31,53,66] Calculation of analytical variables has been previously described.[11] Briefly, the vertical velocity of the body center of mass was obtained by time integration of the instantaneous acceleration. Either the trial with the highest jump height, due to instructions to jump as high as possible, or highest peak power if all jump trials/participant were without flight, was selected for analyses, with 2.1% (N=26/1,268) excluded for technical and data processing problems with all trials. Body weight recorded during each test was used to standardize peak power and force at peak power. Analytic variables from selected trials were peak power (Watts/kg body weight), velocity (m/s) at peak power, and force (Newton/kg body weight) at peak power. Jump measures in a small subset had high reproducibility and reliability.[11] Participants with jump measures (N=1,242) were more likely than those without jump tests (N=573) to complete grip strength (98% vs. 84%; $p<0.05$) and all physical performance measures (400m walk time: 95% vs. 43%; gait speed: 99% vs. 87%; chair stands speed: 96% vs. 54%; all $p<0.05$) (Table 16).

10.4.3 Grip Strength/kg

Jamar dynamometers (Sammons Preston Rolyan, Bolingbrook, IL, USA)[174] were used to measure grip strength for two trials of both hands. Maximum grip strength was normalized to body weight (kg/kg body weight). After exclusions for recent hand pain/arthritis symptoms (N=46/1,841; 2.5%), hand surgery in the past 3 months (N=1/1,841; 0.05%), refusal (N=39/1,841; 2.1%), unable (N=25/1,841; 1.4%), or missing (N=1/1,841; 0.05%), grip strength data were available in 93.9% (N=1,729/1,841).

10.4.4 400m Walk Time

Time to walk 400m (10 laps on 20m course) at the participant's usual pace without overexertion was recorded (N=1,447/1,841;78.6%).[172] Exclusions were for inability to attempt the test due to use of a walking aid other than a single straight cane (N=86/1,841; 4.7%), safety (N=71/1,841; 3.9%), shortened clinic visit (N=50/1,841; 2.7%), course obstruction/unavailability (N=2/1,841; 0.1%), refusal (N=79/1,841; 4.3%), or other (N=13/1,841; 0.7%). Participants could rest for ≤60 seconds at any time during testing (without leaning on surfaces or sitting). Testing was stopped (N=93/1,841; 5.0%) for distress (e.g., labored breathing, confusion, unresponsiveness), pain, resting >60 seconds, leaning on a surface twice during rest, requesting an assistive device other than a single straight cane, or requesting to stop.

10.4.5 Gait Speed

Time to walk 6m at the participant's usual pace was recorded.[175] Gait speed was calculated from the fastest time of two trials (m/sec) (N=1,763/1,841; 95.8%). Exclusion was for inability to attempt the test (N=78/1,841; 4.2%).

10.4.6 Chair Stands Speed

Ability to rise once from a standard chair, and time to complete 5-repeated stands, without using arms were recorded (N=1,524/1,841; 82.8%). Exclusions were for missing data (N=1/1,841; 0.05%), inability to attempt the test (N=106/1,841; 5.8%) or refusal (N=21/1,841; 1.1%). Men who attempted but did not complete the initial chair stand (N=160/1,841; 8.7%) or 5-repeated stands (N=29/1,841; 1.5%) were included in analyses with a value of 0 stands/second.

10.4.7 Covariates

Age, race, smoking status (current/past/never) and alcohol consumption (number of drinks/day),[176] any hip/joint pain in the past year and ≥1 fall in the past year were obtained from self-administered questionnaires. Body Mass Index (BMI) was calculated from weight (balance beam or digital scales) and height (Harpenden stadiometers; Dyved UK). Physical activity (PA) total energy expenditure was collected from accelerometry (SenseWear armband; Body Media, Inc., Pittsburgh, PA; N=1,088).[189] Average systolic and diastolic blood pressures (SBP; DBP) were measured with BP Tru automated blood pressure monitors (Coquitlam, British Columbia, Canada).[190] Total hip bone mineral density (BMD) was assessed by dual energy X-ray absorptiometry (Hologic, Inc, Waltham, MA, USA).[191] Global cognitive testing was performed using the Teng Modified Mini-Mental State (3MS) Examination[173] and executive function was measured using Trails B[192] completion time. Comorbidities included diabetes and hypertension (self-report physician diagnosis and/or medication use), and self-reported history of congestive heart failure (CHF), myocardial infarction (MI), stroke and Parkinson's Disease. Total number of medications was calculated from current prescription medications brought to the clinic visit.[193]

10.4.8 Statistical Analyses

Descriptive statistics included two-sided t-tests and Chi-square tests of proportions to compare characteristics at the 2014-2016 clinic visit in men with jump measures (N=1,242) to those without jump tests (N=573). Those with jump measures were stratified by gait speed to compare gait speed ≥1.0 m/s (N=994/1,242) vs. <1.0 m/s (N=246/1,242).[194] To determine if participants with jump measures and impaired function were comparable to those who did not complete jump tests, we compared two gait speed groups ≥1.0 m/s and <1.0 m/s vs. without jump tests. The percent completing grip strength and physical performance measures were compared to percent completing jump tests. Partial Pearson correlations were calculated between jump measures, grip strength and lower-extremity physical performance, and adjusted for age, race, site and height. Correlations with jump velocity were additionally weight-adjusted since velocity was not weight-corrected. Separate stepwise multivariable-adjusted linear regression models were built to evaluate associations per standard deviation (SD) of jump measures and grip strength with physical performance. Covariates with $p<0.10$ in any model (age, race, site, height, falls history, SBP, DBP, hip/joint pain, BMD, Trails B, diabetes, hypertension, CHF, MI, stroke, Parkinson's Disease, and total number of medications) were retained in all final models. Standardized β coefficients were reported to compare results across all models. As a sensitivity analysis for the subset with the accelerometry measure (N=1,088), PA was added to final models. Analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC).

10.5 Results

All men with jump measures (N=1,242), as well as those with gait speed ≥1.0 m/s (N=994), were younger, had lower BMI, higher PA, higher DBP, higher SPB (gait speed ≥1.0 m/s only), less hip/joint pain, better cognitive/executive function, lower prevalence of history of falls, fewer comorbidities, fewer medications, higher grip strength and better physical performance vs. men without jump tests (N=573) (Table 17). Compared to men with jump measures and gait speed <1.0 m/s, those with gait speed ≥1.0 m/s were younger, had lower BMI, higher PA, higher DBP, higher BMD, better cognitive/executive function, fewer comorbidities, fewer medications, and higher power/kg, velocity and force/kg. Those with jump measures and gait speed <1.0 m/s were younger (85±4 vs. 86±5 years), had lower prevalence of history of falls (36% vs. 51%) and slower gait speed (0.88±0.10 vs. 0.92±0.26 m/s) vs. without jump tests.

Jump power/kg was moderately correlated with grip strength/kg (partial $r=0.44$; $p<0.001$) and all physical performance measures (range: partial $r=0.44$ to 0.51; all $p<0.001$) (Table 18). Jump velocity was also moderately correlated with all physical performance measures (range: partial $r=0.41$ to 0.45; $p<0.001$), but only weakly correlated with grip strength/kg (partial $r=0.34$;

p<0.001). All correlations of jump force/kg and grip strength/kg with physical performance (range: partial r=0.20 to 0.33; all p<0.001) were weaker, as was the correlation of these strength measures to each other (partial r=0.24; p<0.001). In adjusted linear regression with standardized βs, 1 SD lower jump power/kg was associated with longer 400m walk time (β=0.47), slower gait speed (β=0.42), and slower chair stands speed (β=0.43) (Figure 8; all p<0.05) after adjustment. Jump velocity results were similar (400m walk time: β=0.42; gait speed: β=0.38; chair stands speed: β=0.37; all p<0.05), while jump force/kg was more weakly associated with physical performance (range: β=0.18-0.24; all p<0.05). Similarly, grip strength was more weakly associated with physical performance (range: β=0.23-0.28; all p<0.05) vs. jump power/kg and velocity. Both jump force and grip strength had typically 50% lower βs compared to jump power/kg and velocity associations with performance. Results were not attenuated when PA was added to final models (data not shown).

10.6 Discussion

Jump power/kg and velocity at peak power had magnitudes of associations with physical performance that were approximately 2-fold higher compared to jump force/kg and grip strength/kg. To our knowledge, this study is the first to compare jump power, as well as its distinct velocity and force components, to grip strength and multiple physical performance measures in a large multicenter epidemiologic study. Previous studies relating jump tests to physical performance have not included the oldest adults or participants unable to lift their feet off the ground.[61,168,169,185] These previous studies likely excluded individuals with worse physical function resulting in samples with narrower ranges of physical performance that are not representative of the population with mobility limitation. Our study had a wide range of function; 20% of men with jump tests had gait speed <1.0 m/s and 28% had ≥1 jump without flight,[11] suggesting that our more inclusive methodology may be more appropriate for individuals with poorer function and/or risk for future functional decline. Functional, task-based power methods (e.g., jump tests) may more closely approximate the ability to perform activities of daily living compared to traditional strength measures because the velocity of movement is incorporated. Weight-bearing tests, such as jump tests, should be considered in studies of muscle function, especially for individuals excluded from seated tests (e.g., those with certain joint conditions, such as arthritis) and studies focused on performance-based outcomes.

Power and the velocity component for generating movement may be more important factors necessary for preventing functional loss at the oldest ages compared to force or strength. However, the relationships of power, velocity and force with physical performance have not been previously included in one single study. In an earlier small study in men (N=37, mean age: 80±1 years), velocity measured with seated leg press showed only a slightly higher association with 400m walk gait speed (standardized $\beta=0.42$, $p=0.005$) than strength (standardized $\beta=0.36$, $p=0.02$), but the relationship of power to physical performance was not reported.[145] Two past studies of men and women aged 72±5 years (range: 69-81 years)[169] and 65±17 years (range 27-96 years)[61] reported unstandardized estimates and showed that power/kg and velocity were only weakly correlated with walking (6 minute distance[169] and usual gait speed[61]); though moderately correlated with chair stands.[61] Our study had a similar mean and range for gait speed as this past study, though included only men at older ages (77-101 years) with a wider range of function.[11] We compared standardized estimates across various physical performance measures since power, velocity, force and grip strength each have distinct measurement units. Another study of women aged 76±3 years (range 71-87 years) that included jump tests compared standardized estimates and showed that lower jump power/kg was 3 times more strongly related to slower gait speed and 2 times more strongly related to chair stands time vs. jump force/kg.[168] We found estimates of jump power/kg and force/kg to physical performance with similar magnitudes as the previous studies, suggesting the velocity component of power, rather than the force component, is likely more crucial for movement, and therefore physical function, in the oldest adults. The jump test may more closely estimate physical performance than seated muscle power tests or grip strength due to other neuromuscular factors (e.g., balance) that are required to complete this task-based, weight-bearing measure.[182,184]

Muscle power may be an earlier predictor of age-related muscle function loss vs. strength alone. The age-related decrease in area of Type II muscle fibers responsible for generating short, quick bursts of movement[1] may explain larger declines in muscle power and velocity compared to force. Past studies showing substantially lower power at older ages vs. younger ages than strength[11,13-16,66] have rarely included adults >80 years. However, in our previously published study of MrOS men aged 77-101 years, for each 5-year increase in age, power/kg was 10% lower and velocity was approximately 7% lower, whereas force/kg was 3% lower.[11] Differences in power and velocity by age were even higher in magnitude in those >90 vs. ≤80 years old (power: 30% lower; velocity: 24% lower; force/kg: 9% lower).[11] As jump power and velocity may have larger age-related declines than jump force, these may be more strongly related to physical performance than strength.

10.6.1 Strengths

Unlike many previous large epidemiologic studies in older adults, we had multiple measures of both muscle function and physical performance. Only a few studies measured both lower-extremity muscle power and upper-extremity grip strength in association with physical performance.[61,76,152] However, these studies measured power in a seated position[76,152] and did not calculate or compare both power and force to physical performance.[61,76,152] The novel force plate methodology developed for this study allowed inclusion of individuals unable to jump (i.e., unable to lift the feet off the ground). Among the oldest old ranging from 77 to 101 years, this method allowed us to include those who performed jump tests despite poor function (gait speed <1.0 m/s), but similar health (e.g., diabetes, hypertension and myocardial infarction) and physical function (e.g., grip strength, 400m walk time and chair stands speed) to those without jump tests. MrOS also collected data on many covariates to adjust for independent associations of jump test measures and strength with physical performance.

10.6.2 Limitations

The cross-sectional study design does not allow us to establish temporal relationships or examine longitudinal decline in muscle function associated with performance-based measures. Our conservative approach for safety may have excluded some participants able to jump, largely for balance issues as evidenced by 51% of excluded men with falls in the past year vs. 34% with jump tests. Excluding these frail men limits generalizability. Additionally, our community-dwelling, largely white population of men limits generalizability. The time intensive data processing of jump trials due to custom-designed engineering algorithms limited feasibility for many large studies and immediate clinical application. Other muscle power measures were not collected and therefore were unable to be compared to jump power.

10.6.3 Conclusions

Jump test measures of lower-extremity power/kg and velocity at peak power had a two-times higher association with multiple physical performance measures than jump force/kg or grip strength/kg. Weight-bearing power and velocity may be stronger predictors of poor physical performance than strength in the oldest adults. Functional power from weight-bearing tasks should be evaluated in diverse populations to determine if similar relationships are observed in a wider age range of older adults, women, or other race/ethnic groups. Future longitudinal studies should determine whether jump power and velocity are stronger predictors of physical performance decline and disability, such as loss of mobility, than jump force or traditional power/strength measures. If results are confirmed, interventions aimed at improving power and velocity may result in improved physical performance.

10.7 Disclosures, Funding and Acknowledgments

10.7.1 Disclosure of Potential Conflict of Interest

We have no conflicts of interest to declare. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (University of Pittsburgh Institutional Review Board, Committee D,

IRB # REN18050217 / IRB980305) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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10.8 Tables and Figures

Table 16. Number (percent) of men with complete tests of grip strength and physical performance by jump test completion*

%	Total with jump measures (N=1,242)	Total without jump tests (N=573)
Grip strength	1,222 (98.4)	481 (83.9)
400m walk time	1,174 (94.5)	248 (43.3)
6m usual gait speed	1,240 (99.8)	497 (86.7)
Chair stands speed	1,191 (95.9)	309 (53.9)

*All completion rates $p<0.05$ comparing participants with jump measures vs. without jump tests

Table 17. Characteristics of men by jump test completion and gait speed

	Total with jump measures			
mean±standard deviation or %	All (n=1,242)	Gait speed ≥1.0 m/s (N=994)	Gait speed <1.0 m/s (N=246)	Total without jump tests (n=573)
Demographics				
Age, years	84±4*	83±4*,†	85±4*	86±5
White race, %	90	90	90	93
Anthropometry				
Height, cm	172.5±6.6*	172.6±6.6*	171.9±6.5	171.7±7.4
Weight, kg	79.2±12.1*	78.8±12.0*,†	80.7±12.5	81.3±713.6
Body Mass Index, kg/m^2	27±4*	26±3*,†	27±4	28±4
Lifestyle characteristics				
Current smoker, %	1	2	0	1
≥1 alcohol drink/week, %	52	54*	42	42
Physical activity, kcal/day	2177±365*	2200±371*,†	2080±320	2076±386
Clinical measures				
Systolic blood pressure, mmHg	128±18	128±18*,†	126±18	126±21
Diastolic blood pressure, mmHg	72±11*	72±11*,†	70±11	71±11
Bone mineral density, g/cm^2	0.93±0.15	0.94±0.14†	0.91±0.16	0.92±0.16
Hip/joint pain, %	27*	26*	32	38
Teng 3MS, score	92.6±6.8*	93.1±6.4*,†	90.9±8.1	89.9±9.0
Trails B, seconds to complete	136±67*	128±63*,†	166±74	163±77
Falls history				
≥1 fall in past year, %	34*	33*	36*	51
Comorbidity				
Diabetes, %	15*	13*,†	22	22
Hypertension, %	53	51*,†	60	57

Table 17 Continued

Congestive heart failure, %	7*	6*,†	11	13
Myocardial Infarction, %	12*	11*,†	15	19
Stroke, %	4*	4*	5	8
Parkinson's Disease, %	1*	1*	2	3
Medications				
Total medications, #	8.8±5.4*	8.6±4.8*,†	9.3±4.4	9.9±4.9
Muscle function				
Peak power, W/kg body wt	20.8±5.3	21.8±5.1†	16.5±4.1	-
Velocity at peak power, m/s	1.2±0.3	1.3±0.2†	1.0±0.2	-
Force at peak power, N/kg body wt	16.7±1.9	16.9±1.9†	15.8±1.7	-
Grip strength, kg/kg body wt	0.5±0.1*	0.5±0.1*,†	0.4±0.1	0.4±0.1
Physical performance				
400m walk time, seconds	396±85*	374±59*,†	499±112	488±153
6m usual gait speed, m/s	1.18±0.22*	1.25±0.17*,†	0.88±0.10*	0.92±0.26
Chair stands speed, #/s	0.42±0.14*	0.44±0.13*,†	0.30±0.14	0.25±0.19

*p<0.05 for all with jump measures, gait speed ≥1.0 m/s and gait speed <1.0 m/s vs. total without jump tests (N=26 excluded for data quality); †p<0.05 gait speed ≥1.0 m/s vs. gait speed <1.0 m/s (N=2 missing gait speed)

Table 18. Pearson correlations between jump measures, grip strength and physical performance*

	Velocity, m/s	Force, N/kg body wt	Grip strength, kg/kg body wt	400m walk time, s	6m usual gait speed, m/s	Chair stands speed, #/s
Power, W/kg body wt	**0.87**	**0.56**	**0.44**	**-0.51**	**0.44**	**0.47**
Velocity, m/s		0.10	0.34	**-0.45**	**0.41**	**0.43**
Force, N/kg body wt			0.24	-0.29	0.20	0.27
Grip strength, kg/kg body wt				-0.33	0.28	0.26

r<0.4 weak, **r ≥0.4 to ≤0.6 moderate, r>0.6 strong**; *p<0.001 for all correlations adjusted for age, race, site and height, and weight (velocity only since this measure was not weight-corrected)

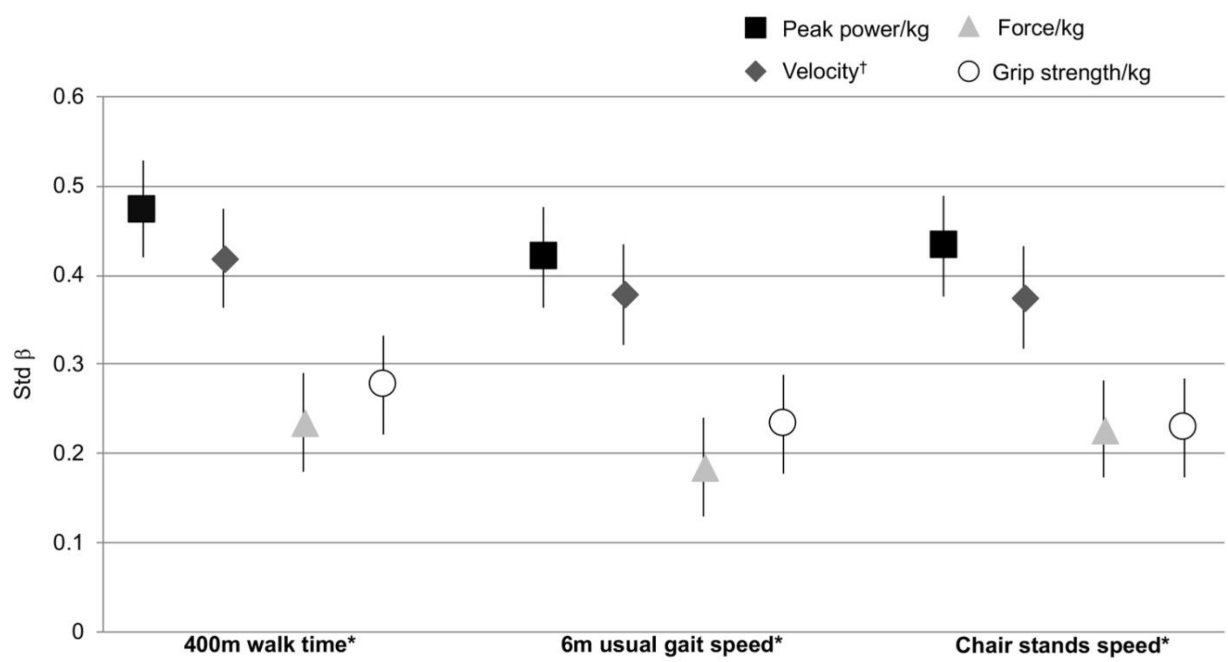

Figure 8. Associations of jump measures and grip strength with physical performance (standardized βs and 95% CI)

*$p<0.05$ for all jump measures and grip strength/kg, adjusted for age, race, site, height, falls history, SBP, DBP, hip/joint pain, BMD, Trails B, diabetes, hypertension, CHF, MI, stroke, Parkinson's Disease and total number of medications; †additionally adjusted for weight

11.0 Lower Leg Power and Grip Strength Are Associated with Increased Fall Injury Risk In Older Men: The Osteoporotic Fractures in Men (MROS) Study

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11.2 Abstract

Introduction: Lower-extremity muscle power, which incorporates strength and velocity, may be more related to fall injury risk compared to strength. However, past research has not investigated both upper-extremity strength and lower-extremity muscle power in relation to fall injuries. Additionally, few studies have examined power and grip strength related to non-fracture fall injuries.

Methods: In the Osteoporotic Fractures in Men (MrOS) Study (baseline: N=5,994; age 73.7±5.9 years; 10.2% minorities), fall injuries (yes/no; non-fracture fall injury and/or fracture) were assessed prospectively from questionnaires administered approximately every 3 years over 9 years. Maximum leg power (Watts/kg body weight) from Nottingham single leg press and maximum grip strength (kg/kg body weight) from handheld dynamometry were assessed at baseline and standardized to body weight.

Results: Of men with fall injury data on ≥1 of 4 follow-up visits after baseline (N=5,178; age: 73.4±5.7), 40.4% (N=2,090) had ≥1 fall injury over the follow-up. Leg power and grip strength were moderately correlated (r=0.44; p<0.0001). Men with fall injury had lower leg power/kg (2.47±0.68 W/kg vs. 2.59±0.70 W/kg) and grip strength/kg (0.50±0.11 kg/kg vs. 0.52±0.11 kg/kg) at baseline compared to those without fall injury (all p<0.05). In generalized estimating equations with unstructured correlation, 1 standard deviation (SD) lower power/kg was associated with a 19% increased fall injury risk (OR=1.19, 95%CI: 1.1-1.3) in models adjusted for age, race, site, height, and comorbidities. Men with lower power/kg had significantly increased fall injury risk vs. highest quartile (Q1 Odds Ratio (OR) per 1SD decrease=1.5, 95%CI: 1.3-1.8; Q2 OR=1.3, 95%CI: 1.1-1.5; Q3 OR=1.2, 95%CI: 1.1-1.4) with significant trend across quartiles ($p<0.0001$). Results were similar for continuous grip strength (OR per 1SD decrease=1.6, 95%CI: 1.1-1.2) and grip strength quartiles (Q1 OR=1.5, 95%CI: 1.3-1.7; Q2 OR=1.2, 95%CI: 1.1-1.4; Q3 OR=1.1, 95%CI: 0.9-1.2; all $p<0.0001$ except Q3 vs. Q4), but trend across quartiles was insignificant ($p>0.05$). In models with both leg power/kg and grip strength/kg, risk estimates were similar for leg power/kg (OR=1.13, 95%CI: 1.06-1.20) and grip strength (OR=1.11, 95% CI: 1.05-1.17). Results were consistent when stratified by type of fall injury.

Conclusions: Lower leg power/kg and grip strength/kg were independently associated with increased fall injury risk. Poorer muscle function, both lower power or strength, may predict higher future fall injury risk in older men.

Key words: Leg power, muscle, upper-extremity strength, fall injury, non-fracture fall injury

11.3 Introduction

Both muscle power and strength may be independently related to critical geriatric outcomes, such as falls that result in injuries, including non-fracture fall injury (NFFI) and fracture. Lower-extremity muscle power (force*velocity) is defined as the ability to exert force quickly[32] and has been related to chronic conditions, such as osteoarthritis, diabetes mellitus, and cardiovascular disease in the aging populations[195]. While both muscle power and strength are lower at older ages compared to younger ages, larger magnitudes of age-related decline have been described for power than for strength.[11,13-16,66] Therefore, power rather than strength may be an earlier indicator of age-related loss in muscle function and potentially increased risk for falls and fall injuries.

Falls are the leading cause of both fatal and nonfatal injuries in older adults and 37.5% of fallers reported fall injuries that required medical treatment or restricted activity for at least 1 day.[18] Recent findings have also noted a distinct increase in number and cost of fatal and non-fatal medically treated fall injuries.[196] Importantly, these fall-related injuries have been linked to mortality, morbidity, and disability.[19,114] Therefore, establishing the risk factors for NFFI and fractures may inform disability and mortality prevention in older adults. Falls are common in older adults with 20-35% self-reporting at least one fall annually.[18-24] Lower leg power and strength[45,197] and grip strength[198,19] have been related to falls in cross-sectional studies of older adults. While a few studies have indicated that lower leg power,[199] grip strength[19] and poor physical performance[163,200] were associated with fall injuries, these past studies have typically only included fracture outcomes though not NFFI. Additionally, past studies have not compared both upper-extremity and lower-extremity muscle function in relation to fall injuries in a single study.

We previously found that higher leg power was significantly related to 18% lower fall risk over 4.5 years in community-dwelling men in the Osteoporotic Fractures in Men (MrOS) Study.[105] However, injuries resulting from these falls, which are important clinical indicators of fall severity, were not examined. We prospectively examined the relationship of baseline leg power and grip strength with incident fall injuries, including both NFFI and fractures, in a large population of older community-dwelling men. We hypothesized that lower leg power and lower grip strength would be associated with higher fall injuries over 9 years, independent of physical performance.

11.4 Materials and Methods

11.4.1 Study Population

The Osteoporotic Fractures in Men (MrOS) Study (http://mrosdata.sfcc-cpmc.net) is a multicenter longitudinal cohort study designed to evaluate healthy aging with a particular focus on risk factors for osteoporosis and fractures. Baseline visits occurred between March 2000 and April 2002 at six U.S. sites (N=5,994; aged 73.7±5.9 years).[175] Initial eligibility criteria included age ≥65 years, the ability to walk without assistance or walking aid; provide self-reported data and informed consent; residence near a clinical site; and absence of bilateral hip replacement or any severe disease/condition that would result in imminent death. Of 5,994 men at baseline, N=5,178 (86.4%) had fall injury data for ≥1 follow-up questionnaire, the Nottingham leg power measure and grip strength. Nottingham leg power data (Blackwell T et al 2009) was missing for N=420 (7.0%) due to equipment failure and N=89 (1.5%) who were unable/refused. Grip strength data was missing for N=74 (1.2%) who were unable and N=2 (0.02%) who refused and/or had missing data. Fall injury data on follow-up questionnaires were not available in N=231 (3.9%).

11.4.2 Fall Injury

Fall injuries were assessed by questionnaires four times spaced approximately 3 years apart over 9 years, including interim questionnaire 1 (July 2002 – March 2004), visit 2 (March 2005 – May 2006), visit 3 (March 2007 – March 2009) and interim questionnaire 2 (March 2009 – February 2011). Any self-reported fall injury in the past 12 months was defined as an affirmative answer to the question: "During the past 12 months, have you fallen and landed on the floor or ground, or fallen and hit an object like a table or chair?" and if yes, subsequently indicating if ≥1 of the following injuries occurred: broken or fractured a bone, hit or injured head, had a sprain or a strain, had bruise or bleeding, and/or other injury (options were not mutually exclusive). Self-reported NFFI were classified as answering affirmatively and subsequently choosing any of the injury options except "broken or fractured a bone". Self-reported fractures were classified as answering affirmatively to any "broken or fractured a bone" response. Although the study did adjudicate fracture outcomes, data collected later in the study may be available to evaluate adjudicated fractures.

11.4.3 Leg Power/kg

The Nottingham Power Rig was used to measure leg extension power (W) at baseline.[45,46,197] Participants were instructed to push the pedal as hard and as fast as possible through a full range of motion, with exclusions for bilateral hip replacement in the past six months. The test was performed on both legs until power plateaued, or up to 5-10 trials to obtain peak power. Maximum peak power was used in analyses and normalized to body weight (W/kg body weight).

11.4.4 Grip Strength/kg

Jamar dynamometers (Sammons Preston Rolyan, Bolingbrook, IL, USA)[174] measured grip strength for two trials of each hand, with exclusions for recent hand pain/arthritis symptoms or hand surgery in the past 3 months. Maximum grip strength was normalized by body weight (kg/kg body weight).

11.4.5 Covariates

All covariates were assessed at the initial clinic visit. Age, race, smoking status (current/past/never) and alcohol consumption (number of drinks per day),[176] and any hip/joint pain in the past year (yes/no) were obtained from self-administered questionnaires. Body Mass Index (BMI) was calculated from weight (balance beams scales) and height (Harpenden stadiometers, Dyved UK). Physical activity (PA) was measured by the Physical Activity Scale for the Elderly (PASE)[201]. Systolic blood pressure in the right and left posterior tibial artery and the right brachial artery were measured twice after the subjects were supine for at least 5 min. Pulses were detected by using a hand held 8 MHz Doppler (Cauley et al 2016). Ankle-brachial index (ABI) was calculated as the ratio of the average systolic pressure in the ankle to the average systolic pressure in the arm. ABI<0.9 defined peripheral vascular disease and ABI>1.3 defined arterial stiffening. Total fat and lean mass were assessed by dual energy X-ray absorptiometry (Hologic, Inc, Waltham, MA, USA).[191] Global cognitive testing was assessed using the Teng Modified Mini-Mental State (3MS) Examination[173] and executive function was measured using Trails B[202] completion time. Serum cystatin C concentrations were determined using a BN100 nephelometer (Dade Behring Inc., Deerfield, IL) using a particle-enhanced immunonepholometric assay.[203] Cystatin C-based eGFR was computed using a CKD-EPI equation re-expressed for standardized cystatin C.[204,205] Comorbidities included diabetes (self-report physician diagnosis, medication use, and/or baseline fasting glucose ≥126 mg/dl), hypertension (self-report physician diagnosis and/or medication use) and self-reported history of congestive heart failure (CHF), myocardial infarction (MI), stroke and Parkinson's Disease. Total number of medications was calculated from current prescription medications brought to the clinic visit.[193] Physical performance measures included 6m usual gait speed, narrow walk gait speed, and chair stands speed from the extended Short Physical Performance Battery (SPPB).[206] Usual gait speed was measured from the fastest time of two trials over 6m. Narrow walk gait speed on a course of 6m × 20cm was used as an indirect measure of dynamic balance and participants were considered able to complete trial if they had no more than two deviations from the lane. For men able to rise once from a standard chair without using arms, time to complete 5-repeated chair stands without using arms was recorded. Men who attempted but were unable to complete a single stand or 5-repeated stands were included in analyses with a value of 0 stands/second.

11.4.6 Statistical Analyses

Descriptive statistics included two-sided t-tests and Chi-square tests of proportions (or Fishers Exact, if appropriate) to compare characteristics at the 2000-2002 clinic visit in men with any fall injury vs. without fall injury. Generalized estimating equations (GEEs) with binomial distributions were used to model the outcome of fall injury during the approximate 9-year follow-up period, with the responses to the fall injury questions over time as repeated assessments. Participants who reported both NFFI and fracture were classified as either NFFI or fracture depending on which injury occurred first. Baseline leg power/kg and grip strength/kg were the primary predictors and were entered both in separate models and additionally together in the same model after assessing correlation between leg power/kg and grip strength/kg. All GEE models were built using an unstructured correlation as this model had the highest Bayesian information criterion (BIC). Models were built for predictors of continuous leg power and grip strength separately and combined, as well as quartiles for each measure. Leg power quartiles (W/kg) were defined as: Q1: ≤2.05; Q2: 2.06-2.53; Q3: 2.54-2.99; Q4: >2.99. Grip strength quartiles (kg/kg body weight) were defined as: Q1: ≤0.44; Q2: 0.45-0.51; Q3: 0.52-0.59; Q4: >059. Q4 represented men with the highest leg power or grip strength and was considered the reference group for analyses. Test of trends across quartiles were done. Baseline covariates were entered using forward stepwise GEE modeling and were retained in all final models if significant at $\alpha \leq 0.10$ in any model. Additional analyses stratified the outcome by type of fall injury and examined NFFI vs. without fall injury and fracture vs. without fall injury. As a sensitivity analysis to determine if physical performance attenuates the relationship between muscle function and fall injury, physical performance measures that were weakly correlated (weak: r≤0.40; moderate 0.40<r<0.60; strong r≥0.60) with leg power/kg or grip strength/kg were added to final models.

11.5 Results

At the initial visit, 20.6% reported a fall and 8.6% reported recurrent falls in the past year (Table 19). Over the 9-year prospective follow-up period, 40% (N=2,090) self-reported any fall injury, 48% (N=1,003) reported an NFFI only, 15% (N=314) reported a fracture only, and 37% (N=773) reported both. Participants who reported both NFFI and fracture were classified as either NFFI or fracture depending on which injury occurred first: 95% (N=732/773) had an NFFI first and 5% (N=41/785) had a fracture first. For the final analytic sample of 2,090 fall injuries, 83% (N=1,735) were NFFI and 17% (N=355) were fractures. An equal number of men with any fall injury and NFFI were in each leg power and grip strength quartile, but fewer men with fractures were in quartile 4 (Table 20). Men with fall injury had lower leg power/kg (2.47±0.68 W/kg vs. 2.59±0.70 W/kg) and grip strength/kg (0.50±0.11 kg/kg vs. 0.52±0.11 kg/kg) compared to those without a fall injury (Table 19). Those with fall injuries were older, more likely to be white, had higher total body fat mass, were less likely to smoke and more likely to use alcohol, and more likely to have hip/joint pain, hypertension, myocardial infarction, stroke, total number of medications, and poorer physical performance.

A 1 SD lower power/kg was associated with a 19% (OR=1.19; 95%CI: 1.1-1.3) increased fall injury risk, adjusting for age, race, site, height, hypertension, stroke and total number of medications (Figure 9). Men in lower power/kg quartiles had a significantly higher fall injury risk compared to men in the highest quartile (Q1 OR=1.5, 95% CI: 1.3-1.8; Q2 OR=1.3, 95% CI: 1.1-1.5; Q3 OR=1.2, 95% CI: 1.1-1.4) with significant trend across quartiles (p<0.001) (Figure 9). Results were similar for grip strength when assessed continuously (OR=1.16, 95%CI: 1.1-1.2, p<0.0001). Compared to results for the leg power quartiles, grip strength quartiles Q1 and Q2 vs. Q4 were similar (Q1 OR=1.5, 95%CI: 1.3-1.7; Q2 OR=1.2, 95%CI: 1.1-1.4 both p<0.0001), but Q3 vs. Q4 was lower (OR=1.1, 95%CI: 0.9-1.2; p>0.05). Also, the trend across grip strength quartiles was insignificant (p>0.05) (Figure 9). Since leg power/kg and grip strength/kg were moderately correlated (r=0.44; p<0.0001), these were entered into the fall injury model simultaneously to determine independent contributions. In models with both leg power/kg and grip strength/kg, fall injury risk estimates per 1 SD decrease were similar and independent of each other for leg power/kg (OR=1.13, 95%CI: 1.06-1.20) and grip strength (OR=1.11, 95% CI: 1.05-1.17).

When stratified by type of fall injury, the magnitude of association for N=1,735 with NFFI vs. without fall injury was approximately 1.5 times higher compared to the association of any fall injury vs. without fall injury (Figure 10). Lower leg power was associated with an increased NFFI risk (OR=1.3, 95% CI: 1.1-1.4) in fully adjusted models. Men in lower power/kg quartiles had significantly higher NFFI risk compared to the highest quartile (Q1 OR=1.4, 95% CI: 1.2-1.7; Q2 OR=1.3, 95% CI: 1.1-1.7; Q3 OR=1.2, 95% CI: 1.0-1.4) with significant trend across quartiles (p<0.001) (Figure 10). The magnitude of association for N=355 with fracture vs. without fall injury was approximately 2.5 times higher compared to the association of any fall injury vs. without fall injury (Figure 11). Lower leg power was associated with an increased fracture risk (OR=1.5; 95% CI: 1.3-1.8) in fully adjusted models. Men in lower power/kg quartiles had significantly higher fracture risk compared to men in the highest quartile (Q1 OR=2.1, 95% CI: 1.4-3.0; Q2 OR=1.8, 95% CI: 1.2-2.6; Q3 OR=1.7, 95% CI: 1.2-2.5) with significant trend across quartiles ($p<0.001$) (Figure 11).

Physical performance measures were weakly correlated with leg power/kg (6m usual gait speed: $r=0.29$; narrow walk speed: $r=0.25$; chair stands speed: $r=0.35$; all $p<0.0001$) and grip strength/kg (6m usual gait speed: $r=0.21$; narrow walk speed: $r=0.21$; chair stands speed: $r=0.26$; all $p<0.0001$) (Table 21). When added to fall injury models, physical performance covariates were not significant in models for leg power/kg or grip strength/kg with fall injury, or in stratified models for NFFI or fracture, and did not attenuate primary results.

11.6 Discussion

Both lower leg power/kg and grip strength/kg were individually and independently associated with increased fall injury risk in men. To our knowledge, this is the first study to prospectively and simultaneously examine the relationships of lower-extremity leg power and upper-extremity grip strength with prospective fall injury risk over nearly a decade. Lower leg power and grip strength were significantly associated with not only fractures, but also NFFI that are not typically included in studies of fall injury in older adults. Results that examined associations with fall injury across muscle function quartiles were similar for leg power and grip strength when comparing groups with better muscle function (Q1 and Q2) to weakest muscle function (Q4), though stronger for leg power when comparing the group with weaker muscle function (Q3) to weakest muscle function (Q4). This suggests that leg power may discriminate better than grip strength for fall injury risk within those with poorer muscle function. In a past

MrOS study, values of jump power had wider ranges in the oldest adults and in those with functional limitations, also suggesting that power may be able to differentiate within poor functioning individuals.[11] These relationships were independent of physical performance measures of gait speed or chair stands speed, indicating that both strength and power may be earlier predictors of fall injury risk than physical performance in older men.

While fall injuries are common in older adult populations, the extent to which muscle function may be related to fall injuries has not been well-studied. In particular, lower-extremity muscle function is necessary for walking and maintaining balance, and therefore necessary for preventing falls and fall injuries. The few past studies of muscle function and fall injury have only included upper-extremity grip strength[199] or surrogate measures of leg muscle function using the chair stands test of physical performance.[163,199] In older men and women (age = 78.1 ± 5.4 years), the slowest chair stand time quartile was associated with higher fall injury risk over 4.3 years compared to the higher quartile groups.[163] Our results of leg power quartiles were similar, though we found higher estimates at each quartile. In one previous study of our MrOS cohort, Nottingham leg power and grip strength were not related to hip fracture in older men over 5.3 years of follow-up.[199] This past study included men at an earlier time point in their aging trajectory, as follow-up was approximately two times shorter than our study. Additionally, studies may need to include older adults with the weakest muscle function to have statistical power for evaluating those at risk of more severe fall injuries (e.g. hip fracture). The follow-up time in our study was approximately twice as long as these past studies and the past MrOS study included these older men at an earlier time point in their aging trajectories compared to our current study. Additionally in the past MrOS study, NFFI were not included as the major focus in fall injury studies of older adults has usually been on very severe fall injuries (i.e., fractures). In our study, NFFI were 3 times more common than fractures (48% with NFFI only vs. 15% with fractures only), and typically occurred earlier than fractures for those with both an NFFI and fracture (N=773 reported both; 95% (N=732/773) had an NFFI first; 5% (N=41/785) had a fracture first). Estimating risk for more comprehensive fall injury outcomes may help assess fall severity and has implications for how different fall injuries may influence disability and mortality outcomes in older adults.

Muscle function impairments precede physical function impairments and disability in older adults (Nagi model of disability). Lower leg power and grip strength were associated with increased fall injury risk independent of physical performance (gait speed and chair stands) in the current study. However, this is in contrast to previous studies examining the relationship of lower leg power with falls,[24,64,149,150,164,165,207,208] fall injuries,[163] or incident radiographic vertebral fracture.[200] Our population likely had a wider range of both muscle function and physical function and assessed muscle power and strength prior to physical performance decline. This allowed us to observe this independent relationship in older men, and would allow more separation of aging populations by muscle and/or physical function.

11.6.1 Strengths

The prospective design over 9 years allowed an assessment of fall injury risk in a large sample of men aged 70 years and older who are at high risk for falls and the associated injuries. Collection of leg power and grip strength allowed comparison of both upper-extremity and lower-extremity muscle function with fall injury risk. The prospective questionnaires utilized were not limited to fractures as information on other NFFI such as sprains, strains, bruises and contusions were also collected. MrOS also collected data on many covariates to adjust for the independent associations of muscle power and strength with fall injury.

11.6.2 Limitations

Our fall injury outcomes, including fractures, were based on self-report only and were not adjudicated or validated with medical records. Fall injuries in the past 12 months were likely underreported since collection was approximately every 3 years. Recall or reporting bias may have led to either underestimation or overestimation of fall injuries. Data collected later in the study may be available to evaluate adjudicated fractures. Power was measured with a seated power test that may exclude older adults unable to get into the seated position, with difficulty sitting or pushing in the required positions with fixed hip and knee angles or those with certain joint conditions, such as arthritis. The community-dwelling, largely white population of men healthy enough to attend a clinic visit limits generalizability. By excluding those who are extremely frail or physically impaired and could not attend a visit, we likely observed more moderate fall injury risk estimates.

11.6.3 Conclusions

Leg power and grip strength were related to increased fall injury risk, including both NFFI and fracture, in separate models. Poorer muscle function, both power or strength, may predict higher risk of future fall injury in older men.

11.7 Tables and Figures

Table 19. Descriptive characteristics of men by fall injury status

% or mean ± standard deviation	Total (N=5,178)	Any Fall Injury. (N=2,090)	No Fall Injury (N=3,088)
Demographics			
Age at baseline, years	73.4 ± 5.7	74.0 ± 5.8*	72.9 ± 5.6
White race, %	89.8	91.9*	88.4
Anthropometry			
Height, cm	174.4 ± 6.8	174.3 ± 6.9	174.3 ± 6.7
Weight, kg	83.2 ± 13.0	83.5 ± 13.2	83.0 ±12.9
Body Mass Index, kg/m^2	27.3 ± 3.7	27.4 ± 3.8	27.3 ± 3.7
Total body fat mass, kg	21.7 ± 7.0	22.0 ± 7.2*	21.5 ± 6.9
Total lean mass, kg	57.0 ± 57.1	56.9 ± 7.1	57.0 ± 7.2
Lifestyle Characteristics			
Current smoker, %	5.3	4.2*	5.9
>1 alcohol drink/week, %	53.3	55.7*	51.7
Physical Activity, PASE score	148.8 ± 67.8	146.7± 66.7	150.3 ± 68.6
Clinical measures			
Ankle-Brachial Index			
≤0.9 (low)	5.5	6.1	5.0
1.0-1.4 (normal)	90.7	89.8	91.4
≥1.4 (high)	3.8	4.1	3.7
Hip/joint pain, %	23.0	26.3*	21.2
Teng 3MS, score	93.5 ± 5.6	93.7 ± 5.1	93.4 ± 5.9
Trails B, seconds to complete	130.8 ± 56.3	129.8 ± 54.4	131.4 ± 57.5
Cystatin-C, mG/L	1.0 ± 0.2	1.0 ± 0.2	1.0 ± 0.3
GFR, CKD-EPI cystatin-C equation	73.7 ± 17.5	72.7 ± 17.0	74.5 ± 17.9
History of falls			
Self-reported ≥1 fall in past year, %	20.6	29.3*	14.9
Self-reported ≥2 falls in past year, %	8.6	13.9*	5.0
Comorbidities			
Hypertension, %	42.2	44.3*	41.0
Diabetes, %	14.6	15.3	14.2
Congestive heart failure, %	4.5	5.0	4.2
Myocardial infarction, %	12.9	14.8*	11.6
Stroke, %	5.1	6.1*	4.4
Parkinson's Disease, %	0.7	0.9	0.6
Medications			
Total # of medications	4.0 ± 3.5	4.5 ± 3.9*	3.7 ± 3.3
Physical performance			
6m usual gait speed, m/s	1.26 ± 0.23	1.25 ± 0.23*	1.27 ± 0.22
Narrow walk speed, m/s	1.16 ± 0.27	1.14 ± 0.27*	1.17 ± 0.26
Chair stands speed, #/second	0.48 ± 0.14	0.47 ± 0.15*	0.49 ± 0.14
Muscle function			
Nottingham leg power, Watts/kg body weight	2.53 ± 0.70	2.47 ± 0.68*	2.59 ± 0.70.
Grip strength, kg/kg body weight	0.51 ± 0.11	0.50 ± 0.11*	0.52 ± 0.11

*p<0.05 for fall injury vs. no fall injury

Table 20. Number of men in leg power in grip strength quartiles, by fall injury outcome

N(%)	Any Fall injury (N=2,090)	NFFI (N=1,735)	Fracture (N=355)
Leg power			
Q1	581 (27.8)	477 (27.5)	104 (29.3)
Q2	546 (26.1)	449 (25.9)	97 (27.3)
Q3	526 (25.2)	434 (25.0)	92 (25.9)
Q4	437 (20.9)	375 (21.6)	62 (17.5)
Grip strength			
Q1	585 (28.0)	475 (27.4)	110 (31.0)
Q2	550 (26.3)	451 (26.0)	99 (27.9)
Q3	496 (23.7)	425 (24.5)	71 (20.0)
Q4	459 (22.0)	384 (22.1)	75 (21.1)

Table 21. Correlations between leg power, grip strength and physical performance*

	Grip strength, kg/kg body weight	6m usual gait speed, m/s	Narrow walk speed, m/s	Chair stands speed, #/second
Leg power, W/kg body weight	0.44	0.29	0.25	0.35
Grip strength, kg/kg body weight		0.21	0.21	0.26

*All correlations adjusted for age and significant at p<0.0001

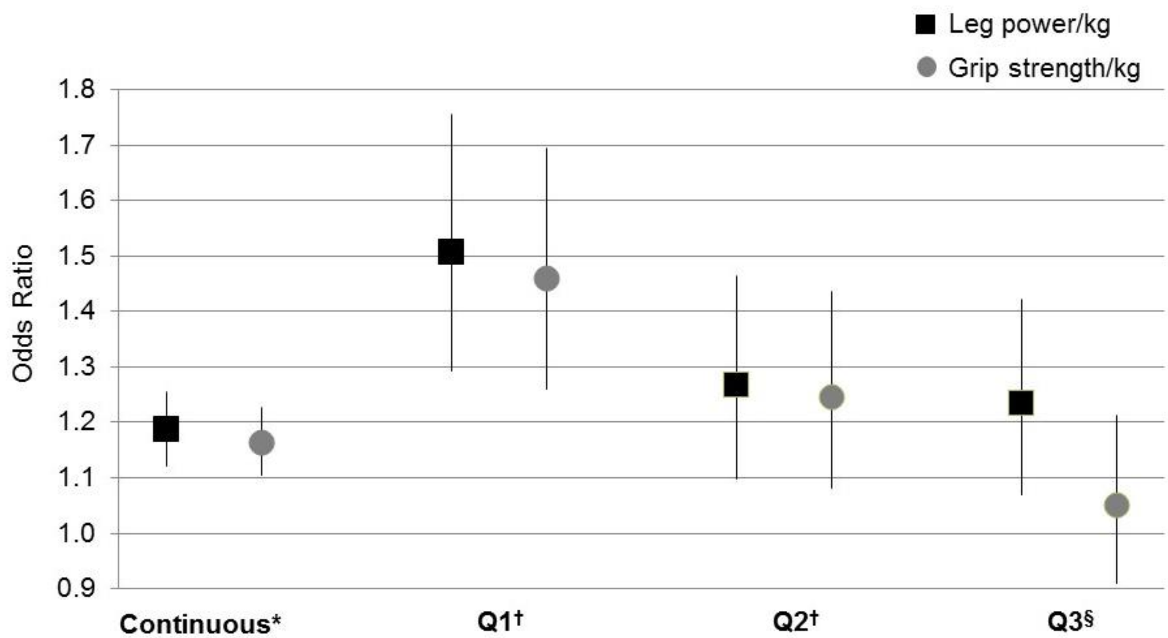

Figure 9. Odds ratio (95% confidence intervals) for leg power and grip strength associated with fall injury

All models adjusted for age, race, site, height, hypertension, stroke and total number of medications; *p<0.05 for leg power/kg and grip strength/kg; †p<0.05 for quartile 1 and quartile 2 vs. quartile 4 for both leg power and grip strength; §p<0.05 for quartile 3 vs. quartile 4 for leg power only (not grip strength).

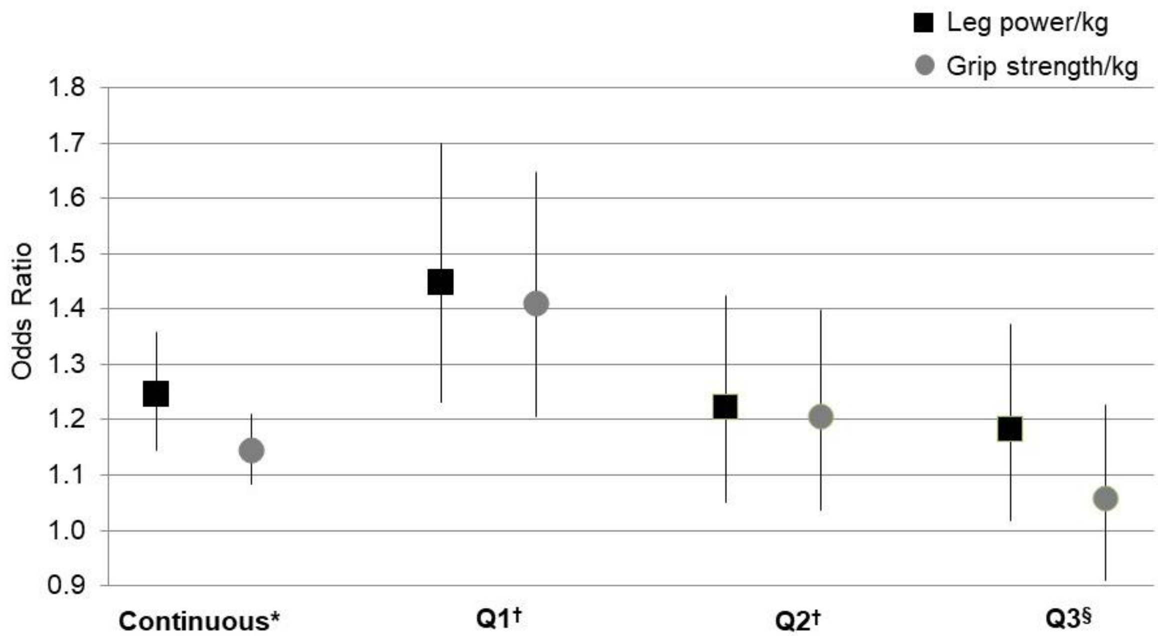

Figure 10. Odds ratio (95% confidence intervals) for leg power and grip strength associated with non-fracture fall injury

All models adjusted for age, race, site, height, hypertension, stroke & total number of medications; *p<0.05 for leg power/kg & grip strength/kg; †p<0.05 for quartile 1 & quartile 2 vs. quartile 4 for both leg power & grip strength; §p<0.05 for quartile 3 vs. quartile 4 for leg power only (not grip strength)

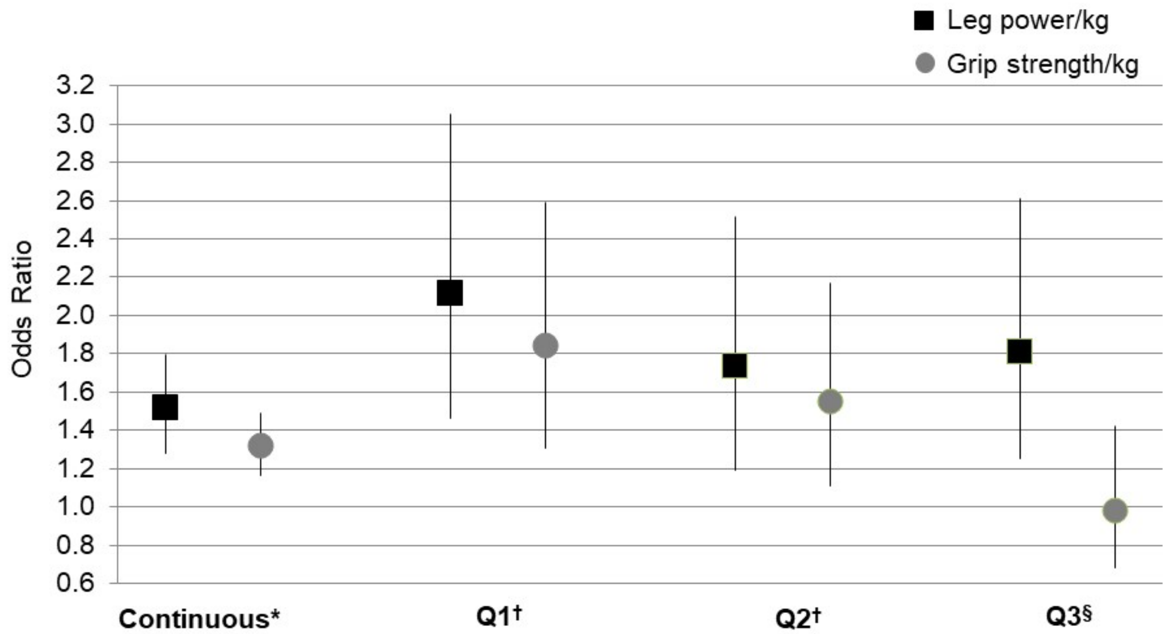

Figure 11. Odds ratio (95% confidence intervals) for leg power and grip strength associated with fractures

All models adjusted for age, race, site, height, hypertension, stroke & total number of medications; *p<0.05 for leg power/kg & grip strength/kg; †p<0.05 for quartile 1 & quartile 2 vs. quartile 4 for both leg power & grip strength; §p<0.05 for quartile 3 vs. quartile 4 for leg power only (not grip strength)

12.0 Discussion

12.1 Summary of Findings

The overall objective of this dissertation was to investigate the associations of muscle function assessed by novel and traditional tests with physical performance and fall injuries in older adults, as these differential associations may be critical to understanding disability outcomes in older adults. In the Nagi Model of Disablement, earlier impairments of a bodily system (e.g., muscle function) may lead to functional limitations (e.g., slow gait speed). In turn, these functional limitations typically lead to disability.[209] Past studies have found inconsistent relationships of muscle power and strength with physical performance.[61,76,144,148,149,152,153,164-169] Our results indicate that functional, task-based power may more closely replicate weight-bearing conditions of physical performance measures. This is possibly due to the different intrinsic properties of power vs. strength and the variability in protocols to test power and strength.[170] Jumping includes both eccentric and concentric muscle action, as well as velocity of movement and other neuromuscular factors (e.g., postural control)[182,184] that are also required to complete physical performance measures, whereas unilateral, non-weight-bearing leg press measures include concentric but not eccentric muscle action in a seated position. Additionally, we found jump power to be more strongly associated with all physical performance than either jump force or grip strength in the MrOS study. However in DECOS, associations of muscle function were differentially associated with physical performance. Both jump power and grip strength were more strongly related to gait speed, and both jump power and leg extension strength were more strongly related to 400m walk time, than the other muscle function measures. Compared to DECOS participants, MrOS participants had not only worse function, but also a wider range of function. A previous MrOS study also found lower jump power values with wider ranges in the oldest adults and those with functional limitations.[11] These results suggest that leg power may be able to discriminate better within poor functioning individuals than strength measures.

Recent findings have noted a distinct increase in the number and cost of fatal and non-fatal medically treated fall injuries,[196] yet muscle function predictors are not well studied despite being related to falls and disability in older adults. Past studies relating muscle function[19,199] and physical performance[163,200] to fall injuries have not typically included NFFI or measured both upper-extremity and lower-extremity muscle function in a single study. Our work showed the extent to which muscle power and strength may be differentially associated with physical performance measures and fall injuries. Overall, lower-extremity muscle function was more strongly related to physical performance than grip strength, but leg power and grip strength had similar associations with fall injury risk. Lower-extremity muscle function tests may be more direct measures of muscle groups needed for physical performance. The lower-extremity muscle groups involved in dynamic, weight-bearing tests are not included in static, grip strength measure. However, grip strength may be proxy measure of lower-extremity muscle function that is related to fall injuries. Therefore, it is critical to select the most appropriate muscle function tests to predict late-life geriatric outcomes, such as functional decline and fall injuries which are important precursors on the pathway to disability.

Our findings suggest that muscle function impairments are related to physical performance, including mobility, in older adults. We examined lower-extremity muscle mechanical power and strength, and upper-extremity muscle strength with standard physical performance tests (400m walk time, 6m usual gait speed and 5-repeated chair stands speed) in older adults. The magnitude of association of jump power and grip strength with faster gait speed was approximately 1.5 to 2-fold higher than each of the traditional lower-extremity measures of muscle function, even after adjusting for potentially confounding factors. Gait speed is commonly considered a representative measure of overall physical function and vital sign related to risk of disability[77,179] in large epidemiologic studies of older adults. In N=3,047 Health ABC participants (age=74.2±2.9 years; 51.5% women, 58.5% white), those with gait speed <1.0 m/s had a higher risk of persistent lower extremity limitation (two consecutive semiannual self-reports of having any difficulty walking one-quarter of a mile or climbing up 10 steps without resting; RR=2.20, 95% CI=1.76-2.74) and persistent severe lower extremity limitation (two consecutive self-reports of having a lot of difficulty or not being able to walk one-quarter of a mile or to climb up 10 steps without resting; RR=2.29, 95% CI=1.63-3.20) than those with gait speed ≥1.0 m/s.[77] In N=6,534 EPESE and Hispanic EPESE participants, those in the slower gait speed quartile had approximately 5 times higher relative risks of mobility-related disability (inability to walk 0.5 mile or climb stairs without help) than those in the fastest gait speed quartile.[179] Jump power or grip strength may be appropriate muscle function measures when the outcome of interest is usual gait speed.

Performance measures assessing fitness and endurance[172,183,210] may have slightly varied associations with muscle function predictors. We found that the magnitude of association of both jump power and Keiser power with longer 400m walk time was higher than other muscle function tests, though each measure was statistically associated with each physical performance test. However, the magnitude of association of jump power with faster chair stands speed was lower than any other power and strength measure. To our knowledge, this is the first study in older adults to compare magnitudes of association for weight-bearing and non-weight-bearing lower-extremity muscle mechanical function, as well as upper-extremity grip strength, with multiple physical performance measures. While jump power and grip strength were more strongly related to usual gait speed, the Keiser leg power assessment may be more appropriate when relating muscle function to 400m walk time or chair stands speed. All DECOS participants had maximum power at 70% of the 1RM. Power assessed with Keiser leg press at 70% 1RM may be more similar to power from task-based power measures (e.g. jump tests), whereas Keiser leg press at lower percentages of the 1RM (e.g. 40%) may be more similar to power from other seated methods (e.g. Nottingham leg press). The choice of muscle function measure should carefully reflect the study focus and population. While each of these associations was statistically significant, the magnitude of the association is critical as it may indicate which muscle function assessment is recommended when studying each physical performance outcome.

In our MrOS analyses, we examined associations of novel jump test measures (jump peak power, and velocity and force at peak power) and grip strength with the same physical performance measures in DECOS. Jump power/kg and velocity at peak power had magnitudes of associations with physical performance that were approximately 2-fold higher compared to jump force/kg and grip strength/kg. To our knowledge, this study is the first to compare jump power, as well as its distinct velocity and force components, versus grip strength and consider multiple physical performance outcomes in a large multicenter epidemiologic study. One past study also found lower jump power was more strongly related to slower gait speed than jump force but did not compare upper-extremity strength to gait speed.[168] The oldest adults or participants unable to lift their feet off the ground, but who were able to be assessed with our novel methods, have not been included in previous studies of the associations between jump tests and physical performance.[61,168,169,185] These past studies potentially excluded individuals with worse physical function, which likely resulted in samples with narrower ranges of muscle function and physical performance that are not representative of the population with mobility limitation. Our study had a wide range of function; 20% with jump tests had gait speed <1.0 m/s and 28% had ≥1 jump without flight.[11] This suggests that our more inclusive methodology may be more appropriate for individuals with poorer function and/or risk for future functional decline. Functional, task-based power methods (e.g., jump tests) may more closely approximate the ability to perform activities of daily living compared to traditional strength measures because the velocity of movement is incorporated. Velocity may be more strongly related to performance outcomes compared to force. Velocity from a seated leg press was previously related to a slightly higher association with 400m walk gait speed than strength but the relationship of power to physical performance was not reported.[145] Weight-bearing tests, such as jump tests, should be considered in studies of muscle function, especially for individuals excluded from seated tests (e.g., those with certain joint conditions, such as arthritis) and studies focused on performance-based outcomes.

We prospectively examined the relationship of baseline leg power and grip strength with incident fall injuries, including both NFFI and fractures, in a large population of older community-dwelling men. Both lower leg power/kg and grip strength/kg were individually and independently associated with increased fall injury risk. To our knowledge, this is the first study to examine the relationships of lower-extremity leg power and upper-extremity grip strength with prospective fall injury risk prospectively for nearly a decade. In one past study, muscle function from chair stands testing, often considered a surrogate measure of leg muscle function, was related to increased fall injury.[163] We also found that lower leg power and grip strength were significantly associated with not only fractures, but also NFFI. NFFI are not typically included in studies of fall injury in older adults, though may be an earlier fall injury outcome than fracture. In our study of fall injuries, 35% (N=7734/85) of participants who reported both NFFI and fracture over 9 years of follow-up had an NFFI first, whereas 2% (N=51/785) had a fracture first. In a past MrOS study, leg power was not related to hip fracture.[199] This past study included men at an earlier time point in their aging trajectory than our study due to a follow-up that was approximately two times shorter. Additionally, studies may need to include older adults with the weakest muscle function to have statistical power for evaluating those at risk of severe fall injuries (e.g. hip fracture). Finally, our relationships of leg power and grip strength with fall injuries were independent of physical performance measures of gait speed or chair stands speed. While both power and strength may be earlier predictors of fall injury risk in older men than physical performance. However, physical function may be a mediator of fall injury risk for the relationship between muscle function and fall injury, which would need to be tested in longitudinal analyses.

12.2 Study Strengths and Limitations

A major strength of our research is that in each study, we compared findings from several different reproducible muscle function tests, including both muscle power and strength as well as both lower-extremity and upper-extremity measures. In the study with fall injury outcomes, we examined not only fractures, but also NFFI that may be clinical indicators of non-fracture fall severity and subsequent disability[211] which many previous studies have not considered. All of the studies also collected data on many covariates to adjust for independent associations of muscle function measures with physical performance and fall injuries. Our physical performance assessments measured usual gait speed from a short distance walking test, mobility from a longer distance walking test that requires endurance, fatigue resistance and aerobic capacity,[183] and speed to rise from a chair. Unlike many previous epidemiologic studies of muscle function and physical performance in older adults, we included three, unique physical performance assessments that have been shown to be precursors to disability[77,179]

Our studies examining associations between muscle function and physical performance have additional strengths. The novel force plate methodology developed for the MrOS study allowed inclusion of individuals who were able to perform jump tests despite poor function (gait speed <1.0 m/s), though had similar health (e.g., diabetes, hypertension and myocardial infarction) and physical function (e.g., grip strength, 400m walk time and chair stands speed) to those without jump tests. Both studies included the oldest old adults with half of the DECOS sample aged 80 years and age range 77 to 101 in MrOS. We likely included individuals who are much higher risk of disability and disease compared to younger old adults due to weaker muscle function, worse physical performance, and higher risk of falls and fall injuries in these oldest age groups. Limitations of these results indicate future directions to address. The community-dwelling, largely white populations used in the studies limits generalizability. The cross-sectional study designs did not allow us to establish temporal relationships or examine longitudinal decline in muscle function associated with performance-based measures. In MrOS, our conservative approach for safety may have excluded some frailer participants able to jump, likely for issues related to loss of balance as evidenced by 51% of excluded men with falls in the past year vs. 34% with jump tests. The time intensive data processing of jump trials due to custom-designed engineering algorithms likely reduce feasibility for many large studies and immediate clinical application. Data processing was especially time-intensive for those with poorest function, whereas the data clean-up for those with better function took less time. For example, algorithms for processing jump trials depended on a stable baseline before jumping started and for those with stability issues, manual investigation of each jump trial was required to enhance algorithms. Finally, other methods for measuring lower-extremity muscle function, such as the stair climb, were not included.

In addition to inclusion of multiple reproducible muscle function tests, an innovative NFFI falls-related outcome and many covariates to adjust for independent associations, our study relating muscle function to fall injuries had a prospective design over 9 years. This long follow-up period allowed an assessment of fall injury risk in a large sample of older men aged 70 years and older who are at high risk for falls and the associated injuries. The study also has limitations. Our fall injury outcomes, including fractures, were based on self-report only and were not adjudicated or validated with medical records, though data collected later in the study may be available to evaluate adjudicated fractures. Fall injuries in the past 12 months were likely underreported since collection was approximately every 3 years. Recall or reporting bias may have led to either underestimation or overestimation of fall injuries. Power was measured with a seated power test that may exclude older adults unable to get into the seated position, with difficulty sitting or pushing in the required positions with fixed hip and knee angles or those with certain joint conditions, such as arthritis. By excluding those who are extremely frail or physically impaired and could not attend a visit, we observed more moderate fall injury risk estimates which likely indicates the risk is higher in frailer, more physically impaired older adults.

12.3 Public Health Significance

Disability is common in the United States. Approximately 26% of adults aged 18 years and older reported a disability, with 14% specifically reporting mobility disability. The prevalence of disability increases with age, as 42% of adults aged ≥65 years reported any disability and 27% reported mobility disability.[212] Since evidence shows that slower gait speed is associated with mobility-related disability[77,179] and mortality,[77,180] maintaining a faster gait speed is critical, especially for older adults. Muscle function impairments, particularly muscle mechanical power and velocity, are potential early predictors of functional impairments. Furthermore, our results found that lower-extremity, weight-bearing measures may be stronger predictors of slower gait speed than non-weight-bearing measures, though similar for long distance walk completion time and chair stands speed. This research shows the importance of considering the protocol and method used to assess muscle function impairments and physical function impairments, two important precursors and predictors of disability.

Falls are common in older adults with 20-35% self-reporting at least one fall annually.[18-24] Falls are also the leading cause of both fatal and nonfatal injuries in older adults and 37.5% of fallers reported fall injuries that required medical treatment or restricted activity for at least 1 day.[18] Importantly, these fall-related injuries have been linked to mortality, morbidity, and disability.[19,114] On the disability pathway, muscle function impairments may lead to a fall injury and consequently disability. By establishing muscle function impairments as risk factors for NFFI and fractures, we may inform disability and mortality prevention in older adults.

In addition to the muscle function impairments we studied, there are other modifiable factors on the pathway to fall injuries, functional limitations and disability. For example, poor balance, physical inactivity and polypharmacy may either lead to or be consequences of muscle function impairments. These neuromuscular and lifestyle risk factors should also be included as targets of prevention of poor geriatric outcomes. With the recently developing public health crisis, the rates of physical inactivity and muscle function decline are increasing, especially in older adult populations. In turn, older adults may experience more fall injury and accelerated physical performance decline, making prevention of disability by targeting modifiable risk factors even more critical.

12.4 Future Directions

The associations of muscle function with physical performance and fall injuries should be further investigated in additional populations of older men and women, with more racial and ethnic diversity. Future studies should examine longitudinal associations of muscle function changes with changes in geriatric outcomes related to physical performance, mobility and falls. Additionally, including jump test methodology to assess power and velocity separately from strength will help in improving our understanding of whether the different aspects of weight-bearing muscle function are differentially associated with these changes in physical performance. New research using the jump test methodology may also consider modifications to reduce exclusions while still ensuring participant safety, especially those with poor balance, such as use of a harness. Automating the data processing of jump tests is necessary for use of these methods in large studies. Including other methods for assessing muscle function, such as Kin-Com leg extension strength or stair climb tests, is important to fully develop this research regarding differential relationships of various muscle function tests to physical performance and fall injuries. Future studies should focus on interventions to maintain muscle function in order to determine if reducing muscle function loss will prevent physical function impairments and ultimately postpone or prevent the development of disability in older adults. Additional targeted populations of older adults with muscle function impairments that may lead to fall injuries later in life should be studied. In particular, those who experience severe fractures and/or severe NFFI such as traumatic brain injuries are likely at the highest risk for these poor health outcomes. Future studies should consider examining not only fractures and NFFI, but also the severity of these events. Objective fall injury data sources, such as medical records or claims data, should be used in conjunction with detailed self-reported fall injury data on fall circumstances, with self-reported outcomes collected frequently in order to reduce recall bias. This will help ensure accurate and complete fall injury information on older adults who may not self-report fall injuries, or may not seek medical attention for NFFI. Future studies of muscle function impairments and fall injuries, by guiding and more comprehensively informing interventions and physical activity recommendations, could potentially reduce not only serious fall injury risk, but also disability and mortality associated with these injuries.

12.5 Conclusion

In order to reduce the prevalence of disability in older adults, we need to understand the early impairments that lead to functional decline and fall injuries in older adults. Functional, task-based power methods (e.g., jump tests) and grip strength may be more strongly related to usual gait speed compared to traditional leg press power and strength in older adults. However, other traditional muscle function tests, such as power and strength measured with leg press methods, may be adequate when studying long distance walk time or chair stand speed. When focusing on jump tests, power and velocity may be more strongly related to physical performance than lower-extremity force or upper-extremity strength. Finally, poorer muscle function, either lower leg power or grip strength, may independently predict higher risk of future fall injury in older men. The public health relevance of these current findings is that identifying potential earlier muscle function predictors of disability may inform prevention efforts that would ultimately reduce disability and mortality in older adults.

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