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Muscle power predicts frailty status over four years: A retrospective cohort study of the National Health and Aging Trends Study

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Abstract

Objectives: Muscle power is a critical measure of physical capacity in older adults, however the association between muscle power and frailty is not well explored. The purpose of this study is to estimate the association between muscle power and frailty in community-dwelling older adults in the National Health and Aging Trends Study from 2011-2015. **Methods**: Cross-sectional and prospective analyses were performed on 4,803 community-dwelling older adults. Mean muscle power was calculated using the five-time sit-to-stand test, height, weight, and chair height and dichotomized into high-watt and low-watt groups. Frailty was defined using the five Fried criteria. **Results**: The low watt-group had higher odds of pre-frailty and frailty at baseline year 2011. In prospective analyses, the low-watt group that was pre-frail at baseline had increased hazards of frailty (AHR 1.62, 95% CI 1.31, 1.99) and decreased hazards of non-frailty (AHR 0.71, 95% CI 0.59, 0.86). The low-watt group that was non-frail at baseline had increased hazards of pre-frailty (1.24, 95% CI 1.04, 1.47) and frailty (1.70, 1.07, 2.70). **Conclusions**: Lower muscle power is associated with higher odds of pre-frailty and frailty and increased hazards of becoming frail or pre-frail over four years in those who are pre-frail or non-frail at baseline.

Keywords: Aged, Chair rise, Frailty, Functional status, Muscle power

Introduction

Frailty is a clinically-defined geriatric syndrome characterized by accumulation of age-related deficits leading to increased vulnerability and impaired resilience following a stressor[1–3]. Frailty is associated with a multitude of negative health outcomes, including falls, disability, and mortality[1–3]. Identification of frailty among older adults is typically assessed using the five Fried et al[1] criteria: exhaustion, slowed gait speed, low physical activity, unintentional weight loss, and weakness[3]. A person is considered non-frail if they demonstrate none of the criteria, pre-frail if they demonstrate 1-2 criteria, and frail if they demonstrate 3 or more criteria[1,3]. Although the prevalence of frailty varies depending upon the method of measurement, recent studies have reported 9.9%-15% of community-dwelling adults over age 65 are frail, and 45% are pre-frail[4–6]. Frailty is a continuum; a person may become more frail as they age, but a person may move from a frail state to a pre-frail or non-frail state with appropriate intervention[1,3]. Better understanding of how movement within this continuum is affected by other

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factors can have significant impact on health and quality of life in older adults.

Although all five Fried et al[1] criteria contribute to frailty classification, weakness is one of the most prevalent in older adults classified as frail or pre-frail[3]. As a result, a physical activity approach, including resistance training, is often taken when implementing prevention and intervention strategies for this population[7]. Recent research has explored the relationship between muscle power and muscle strength as predictors of functional impairment and frailty[8–11]. Muscle strength, measured via grip strength with a dynamometer, is currently used to define the weakness criterion in the Fried et al[1] frailty phenotype. Muscle power, on the other hand, is defined as the rate at which work is performed, and is measured in watts (W) as the product of force times velocity. Although related, muscle strength and muscle power are distinct parameters, and comparison studies have found muscle power may be a more discriminant predictor of overall functional performance in older adults[8,9]. Deficits in muscle power or speed of movement have been also been found to be more highly associated with functional impairments than other physical measures, and more predictive of variance in functional deficits and reported health in the older adult population[8,12,13]. Specific to frailty measurement, muscle power has been associated with both better motor control for gait and reduced gait variability, both of which are related to gait speed, a primary component of frailty measurement[1,13,14]. In consideration of the cycle of frailty cited by Fried[1,15], reduced muscle power as physiologic measure itself may also lie on the pathway to other phenotypic components, including reduced activity level and energy expenditure. Muscle power has also been found to be associated with performance on proxy frailty measures such as the modified Physical Performance Test (mPPT) and short physical performance battery (SPPB)[8,9,12,13,16,17]. Despite its utility in predicting functional outcomes in older adults, however, few studies[12] have assessed the association between muscle power and frailty over time.

Measuring muscle power in practice is a challenge – many methods of muscle power measurement require large, expensive equipment, making these measurements potentially inaccessible in numerous research or clinical settings[18]. Recently, however, Alcazar et al[19] proposed a new, non-instrumented method of muscle power measurement using the five-time sit-to-stand test (STS) in conjunction with body measurements and chair height. The STS is a physical performance measure where the participant is asked to stand up and sit down five times as quickly as possible from a standard-height chair without use of hands, with time taken to complete the task as the recorded score[20–22]. The STS has validated, age-matched norms for community-dwelling adults over the age of 60, as well as cut-off scores used to assess fall risk[21,22]. This method of muscle power measurement has been validated against a leg press with a transducer and a force plate in a population of community-dwelling impaired older adults[19,23], but has not been used in this population prospectively. The purpose of this study is to assess the association between non-instrumented muscle power, frailty, and frailty status changes over a four-year period in a large population of older adults.

Materials and Methods

Study Population

We performed secondary analysis of the National Health and Aging Trends Study (NHATS) years 2011-2015. NHATS is a cohort study of Medicare beneficiaries aged 65 and older with yearly assessments that began in 2011[24]. NHATS uses questionnaires, validated performance-based measures, interviews, physical examinations and biological specimens to collect data[24]. NHATS employs a complex sample design that purposefully oversamples non-Hispanic Blacks and adults over the age of 90 to ensure representation of these groups within the cohort. Our analytical sample (n=4803) included older adults who were community-dwelling or independently living within a facility and had available frailty, muscle power and covariate data for the study period.

Independent variable: Muscle Power

Mean muscle power (W) was calculated as the product of STS mean force and STS mean velocity using the equation described by Alcazar et al (below)[19]. The participant is initially asked to complete one stand without the use of hands. The STS test stops if the participant is unable to perform that task, otherwise up to five repetitive stands are performed and timed for the duration of the task, starting when the examiner says, "go" and stopping once the participant has completed their final stand, but prior to sitting[22,25,26]. The time for task completion is then recorded in seconds; the test ends either when the participant has completed all five stands or if 60 seconds has elapsed[22,25,26]. Participants who are unable to complete a single stand or unable to complete the task in 60 seconds do not receive a score[22,25,26]. The methods for calculating mean muscle force and mean muscle velocity are described elsewhere[19], and this method of muscle power calculation has been validated against two instrumented methods of measuring muscle power in separate subsamples of community-dwelling older adults from the Toledo Study for Healthy Aging[19,23].

$$\textit{STS mean power} = \frac{\textit{Body weight} \times 0.9 \times g \times [\textit{Height} \times 0.5 - \textit{Chair height}]}{\textit{STS time} \times 0.1}$$

Dependent variable: Frailty

Frailty status was operationalized using the method adapted to NHATS by Bandeen-Roche et al[5] based on the five Fried et al[1] criteria: exhaustion, low physical activity, unintentional weight loss, low walking speed, and weakness. Exhaustion was measured via self-report, where the participant responds affirmatively to either "having low energy" or "being easily exhausted enough to limit their activities" Low physical activity was measured via self-report, where the participant responded affirmatively to both, "never walking for exercise" and "never engaging in vigorous activity". Unintentional weight loss is considered positive if a participant responded affirmatively to a weight loss of more than 10 pounds in the past year, and that the weight loss was unintentional. Low walking speed was assessed using the 3-meter walk. In this performance assessment, participants were instructed to walk 3 meters at their "normal pace", with or without using as assistive device. This activity was performed twice, with the second trial used as the scored trial. Participants with a calculated walking speed at or below the 20th percentile of the sample by gender and height were considered positive for this criterion. Weakness was measured as grip strength using a dynamometer and measured in kilograms, where the best of two trials was used. Participants were considered positive for this criterion if they were at or below the lowest 20th percentile for grip strength based on gender and body mass index (BMI) in the sample. Based on these collective assessments, a person was considered non-frail if they demonstrated none of these criteria, pre-frail if they demonstrated 1-2 criteria, and frail if they demonstrated 3 or more criteria[1,27].

Participation in performance measures for frailty assessment was subject to exclusion criteria determined by NHATS: those using a wheelchair or scooter for indoor use or unable to walk a short distance with or without use of a mobility aid (3-meter walk), space limitations (3-meter walk), and those with a recent surgery, flare up of pain in both hands or wrists, or surgery to both arms or shoulders within last 3 months (grip strength)[28]. Once deemed eligible, there were other reasons that performance measure data might be missing, including inability to perform a portion of the measure, safety concerns by the participant, participant proxy (if present), or administrator; inability to complete the measure, or unknown reasons[28]. To maximize inclusion, those participants without performance measure scores due to exclusion criteria, inability to complete part or all of the measure, or due to safety reasons were given a score of "0" (worst possible score). This method was employed by Bandeen-Roche[5] to estimate prevalence of frailty using NHATS data, and it has been recommended for other functional indexes in older adults[26,28].

In our analytical sample, 3.7% (n=179) were missing data on frailty status. To ensure participants were properly categorized, those with missing information on two of the five criteria were considered frail if all three of the available criteria were positive, otherwise they were coded as missing for frailty. Participants with missing information on one of the five criteria were considered frail if at least three were positive, and considered pre-frail if one was positive, otherwise they were coded as missing. For participants with all five criteria recorded, frailty was calculated as described above.

Covariates

All covariates for this analysis were collected in NHATS via self-report. Demographic characteristics included age category (65-69, 70-74, 75-79, 80-84, and 85+), gender, race/ethnicity categorized into Hispanic, Non-Hispanic Black, Non-Hispanic White, and Other Non-Hispanic, and education level categorized into less than high school, high school, some college, and college graduate or above. Health-related characteristics included BMI, depressive symptoms, history of smoking, and comorbidity count. BMI was calculated as kg/m^2 using self-reported weight and height, and then reported using traditional Centers for Disease Control and Prevention (CDC) categories: underweight (<18.5), normal weight (18.5-24.9), overweight (25-29.9), and obese (>30)[29]. Depressive symptoms were calculated using the 6-item Patient Health Questionnaire-2, where a score of 3 or more indicates presence of depressive symptoms[30]. History of smoking was categorized as current, former, and never smokers. Comorbidity count was operationalized as an index of the following health conditions: heart attack, heart disease, hypertension, arthritis, osteoporosis, stroke, and cancer, which was then categorized as 0, 1-2, and 3 or more conditions.

Statistical Analysis

Differences between groups for descriptive characteristics were determined using chi-squared tests for categorical variables. For cross-sectional analyses at baseline, we used multinomial logistic regression to estimate odds ratios comparing the odds of pre-frailty and frailty (compared to non-frail) by muscle power group at baseline. We operationalized muscle power as a binary variable dividing the sample at the weighted median value of 231.2W, resulting in a low-muscle power group (below the median) and a high-muscle power group (above the median). The high-power group was used as the referent, where odds ratios represented the odds of pre-frailty or frailty (compared to non-frail) in the low-power group relative to the high-power group.

To describe the hazard of moving within the frailty continuum over time, we employed survival analysis using Cox proportional hazards regression. Time-to-event was considered to be time to a change in frailty status, or time to a recurrence of frailty status (maintenance). We identified nine separate models to determine the hazard of transitions to each frailty state (non-frail, pre-frail, frail) stratified by baseline frailty status in the low-power group compared to the high-power group. Participants were followed from 2011 until a change in frailty status, maintenance of the same frailty status, loss to follow-up, death, or the end of the study period (2015), a total of four years.

To first determine group differences, we performed Kaplan-Meier estimates and log-rank tests for each event and baseline frailty status subpopulation. Log-rank tests for multiple comparisons between subpopulations for each frailty state transition was also performed, yielding a $p<0.05$

	All n=4803 %, n	Non-frail n=1898 %, n	Pre-frail n=2404 %, n	Frail n=501 %, n	p-value
Watt output					
Above median	49.8 (2614)	61.5 (1096)	44.2 (981)	24.1 (112)	<.0001
Below median	50.2 (2189)	38.5 (802)	55.8 (1423)	74.7 (389)	
Age					
65-69	32.4 (1102)	40.1 (574)	26.7 (448)	24.3 (80)	<0.001
70-74	27.1 (1151)	28.5 (515)	26.7 (544)	22.1 (92)	
75-79	19.6 (1033)	17.6 (386)	21.5 (553)	19.5 (94)	
80-84	13.0 (887)	9.84 (285)	15.1 (488)	17.3 (114)	
85+	7.94 (630)	4.00 (138)	10.0 (371)	16.7 (121)	
Race/ethnicity					
White, Non-Hispanic	83.7 (3491)	87.1 (1474)	82.1 (1709)	74.5 (308)	<0.001
Black, non-Hispanic	7.00 (928)	5.71 (308)	7.50 (485)	10.9 (135)	
Other, non-Hispanic	3.19 (127)	2.88 (45)	3.33 (66)	3.98 (16)	
Hispanic	6.12 (257)	4.33 (71)	6.98 (144)	10.5 (42)	
Gender					
Female	54.1 (2639)	50.0 (971)	56.5 (1361)	61.2 (307)	<.0001
Male	45.9 (2164)	49.9 (927)	43.4 (1043)	38.8 (194)	
Body mass index					
<18.5	1.66 (90)	1.35 (27)	1.79 (51)	2.47 (12)	<0.001
18.5-25	31.1 (1579)	33.4 (661)	29.3 (756)	28.8 (162)	
25-30	39.8 (1863)	43.3 (800)	37.8 (901)	32.7 (162)	
>30	27.4 (1271)	21.9 (410)	30.9 (696)	35.8 (165)	
Education					
Less than high school	18.2 (1055)	12.1 (280)	21.4 (602)	31.6 (173)	<0.001
High school	27.5 (1353)	24.0 (480)	30.0 (716)	32.2 (157)	
Some college	26.7 (1216)	28.2 (513)	26.4 (599)	21.6 (104)	
College +	27.4 (1179)	35.6 (625)	22.2 (487)	14.6 (67)	
Comorbidity Index					
0	11.9 (526)	16.8 (289)	8.78 (216)	4.39 (21)	<.0001
1-2	51.1 (2409)	58.0 (1103)	48.3 (1143)	30.8 (163)	
3+	37.0 (1868)	25.2 (506)	42.9 (1045)	64.8 (317)	
Smoking Status					
Never	46.2 (2295)	46.4 (897)	45.8 (1144)	47.1 (254)	<.0015
Former	45.0 (2113)	47.1 (875)	43.9 (1043)	40.7 (195)	
Current	8.75 (395)	6.46 (126)	10.3 (217)	12.1 (52)	
Depressive symptoms					
No	89.4 (4246)	95.5 (1804)	87.5 (2102)	67.9 (340)	<.0001
Yes	10.6 (557)	4.5 (94)	12.5 (302)	32.1 (161)	

Defn: NHATS: National Health and Aging Trends Survey; NH: non-Hispanic, comorbidity index comprises the following health conditions: heart attack, heart disease, hypertension, arthritis, osteoporosis, stroke, and cancer; presence of depressive symptoms based on a Patient Health Questionnaire-2 score of >3; BMI:body mass index; frailty status determined by possessing a combination of deficits in grip strength, low physical activity, exhaustion, slow walk speed, unintended weight loss where 0= non-frail, 1-2 = pre-frail and 3=frail; analytical sample includes all community dwellers with available frailty data; p-values from chi-squared tests for categorical variables at alpha <0.05; results are weighted means and proportions and unweighted sample sizes.

Table 1. Characteristics of community-dwelling older adults in NHATS at baseline in 2011, stratified by frailty status.

Transition from baseline	Unadjusted (95% CI)	Adjusted (95% CI)
Frail to		
Non-frail	**0.52 (0.27, 0.99)**	0.54 (0.22, 1.34)
Pre-frail	**0.71 (0.53, 0.94)**	0.74 (0.52, 1.06)
Frail	1.12 (0.86, 1.44)	1.12 (0.81, 1.06)
Pre-frail to		
Non-frail	**0.71 (0.62, 0.81)**	**0.71 (0.59, 0.86)**
Pre-frail	1.02 (0.94, 1.11)	1.00 (0.91, 1.11)
Frail	**1.70 (1.39, 2.07)**	**1.62 (1.31, 1.99)**
Non-frail to		
Non-frail	**0.83 (0.76, 0.90)**	**0.86 (0.77, 0.96)**
Pre-frail	**1.19 (1.04, 1.36)**	**1.24 (1.04, 1.47)**
Frail	**1.91 (1.29, 2.81)**	**1.70 (1.07, 2.70)**

Hazard ratios adjusted for the following covariates at baseline: age group, body mass index, gender, depressive symptoms, comorbidities, education, smoking status, and race/ethnicity; NHATS: National Health and Aging Trends Study; CI: confidence interval. ***bold*** *= statistically significant.*

Table 2. Hazard ratios of frailty state transitions in community-dwelling older adults with low muscle power (compared to high muscle power) in NHATS years 2011-2015, stratified by baseline frailty status.

between all groups. We then performed Cox proportional hazards modeling yielding hazards ratios describing the hazards of each frailty state change in the low-power group compared to the high-power group. All analyses were adjusted for statistically significant covariates; statistical significance was calculated *a priori* at p<0.05. For both cross-sectional and prospective analyses, we applied the 2011 analytic survey weights, primary sampling units and strata as recommended by NHATS[31]. All analyses were performed in SAS 9.4.

Results

Characteristics of the total baseline analytical sample and stratified by frailty status are shown in Table 1. The prevalence of low muscle power increased with worsening frailty status- 38.5% of non-frail older adults were in the low-power group, compared to 55.8% of pre-frail and 74.9% of frail older adults (p<.001). The prevalence of negative health indicators also progressively increased with worsening frailty status. Compared to non-frail, pre-frail older adults and frail older adults were more likely to report 3 or more comorbidities (25.2% non-frail, 42.9% pre-frail, 64.8% frail, p<.001) and to report depressive symptoms (4.5% non-frail, 12.5% pre-frail, 32.1% frail, p<.001). Pre-frail and frail older adults were also progressively more likely to be older, female, and have attained lower levels of education compared to non-frail (p<.001).

At baseline, there were statistically significant differences in the adjusted (AOR) odds of being pre-frail and frail (compared to non-frail) in the low-power group compared to the high watt group. The low-power group had 1.82 (95% CI 1.52, 2.17) times the odds of being pre-frail, and 4.33 (95% CI 3.20, 5.88) times the odds of being frail after adjusting for age category, gender, race/ethnicity, BMI, depressive symptoms, smoking status, and education level.

The prevalence of frailty increased with each study year; it was 9% at baseline, 11% in 2012, 12% in 2013, 14% in 2014 and 15% in 2015. The prevalence of pre-frailty stayed consistent throughout the study years being 47% at baseline and 46% each follow up year. As the prevalence of frailty increases, the prevalence of non-frailty decreased: it was 44% at baseline, 43% in 2012, 42% in 2013, 41% in 2014 and 40% in 2015.

Table 2 shows unadjusted (HR) and adjusted (AHR) hazard ratios describing the risk of worsening, improving, or maintaining frailty status comparing the low-power muscle power group to the high-power group. Three proportional hazards regression analyses were conducted for each baseline frailty status (measured in 2011), with a maximum follow-up time of 4 years. For example, among older adults who were not frail at baseline, we modeled the time to becoming pre-frail, the time to becoming frail, and the time maintaining a non-frail status by using separate proportional hazards regression analyses (bottom third of Table 2). Although we refer to a participant who has the same baseline and ending frailty status as having maintained their status, it is possible that unmeasured transitions in frailty occurred over time. Overall, the low-power group had lower hazards of improving frailty status and higher hazards of worsening frailty status over the study period, although in adjusted analyses these findings were only statistically significant for older adults who were pre-frail and non-frail at baseline. After adjusting for covariates, pre-frail older adults in the low-power group had 1.62 times (95% CI 1.31, 1.99) the hazard of becoming frail and 0.71 times (95% CI 0.59, 0.86) the hazard of becoming non-frail compared to the high-power group. Non-frail older adults in the low-power group had 1.24 times (95% CI 1.04, 1.47) the adjusted hazard of becoming pre-frail and 1.70 times (95% CI 1.07, 2.70) the adjusted hazard of becoming frail compared to the high-power group.

The effect of muscle power group on maintenance of frailty status was only statistically significant for older adults who were non-frail at baseline – the low-power group that was non-frail at baseline was less likely to maintain frailty status (AHR 0.86, 95% CI 0.77, 0.96). There was no evidence of an association between muscle power group and maintenance for older adults who were pre-frail (AHR 1.00, 95% CI 0.91, 1.11) or frail (AHR 1.12, 95% CI 0.81, 1.06) at baseline.

Discussion

In this study we performed a secondary analysis of NHATS examining cross-sectional and prospective associations between muscle power output and frailty. We found that community-dwelling older adults with lower muscle power were more likely to be pre-frail and frail at baseline, were more likely to worsen, and less likely to improve their frailty status over a 4-year period than older adults with higher muscle power.

Our results are consistent with instrumented and non-instrumented studies exploring the relationship between muscle power metrics and frailty. Van Roie et al[13] explored the association between maximal speed of movement measured with a dynamometer and physical frailty measured by the Modified Physical Performance Test. They found that mean SoM was lower in those who were pre-frail and frail compared to those who were not frail[13]. In their cross-sectional analysis of muscle power measured using a leg power rig and physical function in mobility-impaired older adults, Bean et al[12] found that lower extremity power was associated with 22-38% of the variance among five functional measures, including measures of balance and the Short Physical Performance Battery (SPPB), also a proxy frailty measurement[26,32].

Two recent studies have explored the relationship between muscle power and frailty using the Alcazar et al[19] method. In their study on relative muscle power (the ratio of muscle power to body mass) using the Alcazar et al[23] method in older adults in the Toledo Study for Healthy Aging (TSHA), Losa-Reyna et al[11] found low relative muscle power was associated with higher odds of frailty in men (OR 4.5, 95% CI 1.1,18.0). This work was expanded upon by Baltasar-Fernandez et al,(11) who, in their cut-point analysis study, found low relative muscle power to be associated with increased odds of being frail in both men (OR 5.6, 95% CI 3.1-10.1) and women (OR 6.9, 95% CI 4.5-10.5) also in the TSHA. Our study, which used the Alcazar et al[19] method to calculate mean muscle power yielding a watt output, adds to and expands on this work. The two aforementioned studies[10,11] operationalized frailty as a 2-category variable, assessing associations between non-frail and frail. We operationalized frailty as a 3-category variable (non-frail, pre-frail, frail), allowing us to distinguish the association of muscle power between pre-frailty and frailty. We found that cross-sectional associations were similar in direction, but magnitude was increased – the odds of being frail versus not frail were higher than the odds of being pre-frail versus not frail in older adults below the median value of muscle power. There were also differences in the effect of muscle power on frailty status in our prospective associations. Overall, older adults in this sample were less likely to improve and more likely to worsen if they generated watt output below the median value for the sample at baseline, however this association was only statistically significant in older adults who were pre-frail and non-frail. Typically, physical function impairments (weakness, slowed gait speed, low physical activity) are the primary characterizations of movement from non-frailty to pre-frailty in community-dwelling older adults, whereas exhaustion and unintended weight loss are more likely to be the "tipping point" for transitions to frailty for this population[3,33]. Our study lends support to these findings. As muscle power serves as a predictor for physical function[8,12], it may be that differences in muscle power output are more influential in non-frail and pre-frail stages, and frail older adults may have a more complex set of impairments that are less affected by muscle power.

There were strengths to our study. We used a prospective design to investigate the association between muscle power and frailty, allowing for a determination of risk. We applied statistical weights to allow for complex survey design which increases generalizability of our results. We operationalized frailty based on the gold-standard Fried et al[1] method, which allowed us to identify separate associations between non-frailty, pre-frailty, and frailty.

There were also a number of limitations. By using Cox proportional hazards modeling we were able to discern the effect of reduced muscle power on frailty state changes over time by treating a frailty status change as a single event and stratifying by baseline frailty status. Frailty, however, is a dynamic process where status changes may be influenced by compounding risks including prior frailty status[3,33,34]. Thus, our results may not be a fully nuanced description of risk in this population.

Our starting sample included only those older adults who resided in the community or lived independently in a community, as these participants undergo physical performance measures at baseline. Thus, our sample was likely healthier and more proficient than the NHATS community-dwelling sample and sample at-large, and we are not able to make determinations about the association between muscle power and frailty status in older adults institutionalized at baseline.

Our frailty assessment used the Fried et al[1] criteria adapted to NHATS by Bandeen-Roche et al(5) which state a participant is "positive" for a criterion if they are at or below the 20th percentile for performance-based measures- in this case, walk speed and grip strength. As such, our sample has a guaranteed prevalence of pre-frailty, as 20 percent of our sample will, by definition, be positive for these criteria. Further work to establish normal values and cut-points for these measures for the older adult population within the context of frailty assessment would advance this field[5].

We operationalized muscle power as a binary variable and made comparisons between older adults above and below the median. This method is based on previous work when assessing the role of muscle power on various outcomes[12,35], and can be beneficial for determining a group at risk or for potential identification of impairments. There are, however, inherent biases that exist when dichotomizing a continuous variable, namely that some respondents may be misclassified as at-risk. Further work to identify an appropriate cut-point or threshold value for muscle power may be needed.

This non-instrumented method of muscle power measurement has been validated against two instrumented methods, however, the assumptions made in its calculation may affect precision of measurement[36]. First, calculating mean muscle power assumes that identical time is taken for each of the five stands, however, it is possible that a participant may speed up or slow down during the examination. Thus, this calculation may not be perfectly indicative of a person's ability to generate power when fatigued. Second, the elimination of 10% of body mass from the equation, purported by the authors as not participatory in the task, may lead to biased results[36]. Lindemann et al[37] noted that, as muscle power from the entire body is required to support the center of mass as it leaves the chair to perform a concentric stand, the total force when moving upward through space should be equal to, if not more than body mass. Thus, muscle power calculations using the Alcazar et al[19] method may be lower than what is actually generated by the participants.

Although they are different metrics, muscle power is physiologically similar to muscle strength, which is included in frailty assessment. Hand grip strength using a dynamometer, which is used to measure muscle strength for frailty assessment in NHATS, has not been found to be significantly correlated with lower body strength or power in older adults[38], however, muscle power has been found to be associated with habitual walking speed, also a component of frailty assessment, in both community-dwelling older adults[39] and those with physical disability[9,40]. These correlations may have spuriously increased the strength of our associations.

A number of our covariates, as well as three of our frailty components (unintended weight loss, exhaustion, and low physical activity) were self-report. In general, self-report of health-related characteristics is can be subject to over- or under-reporting due to social desirability or recall bias[41,42]. Specifically, self-report of physical activity, which could also extend to questions about exhaustion for frailty assessment, is known to be subject to bias, as participants tend to over-report higher intensities and under-report sedentary time[41,42]. This trend could lead to misclassification towards being categorized as non-frail or pre-frail versus frail, leading to a smaller sample of frail older adults and larger samples of non-frail and pre-frail older adults than may exist in the population.

In this study of the association between muscle power and frailty, we found that reduced muscle power was associated with increased odds of pre-frailty and frailty and has an effect on likelihood of improving or worsening frailty status over a 4-year period. Our results add to the body of literature on muscle power and frailty status in the community-dwelling older adult population using a non-instrumented method of muscle power calculation. Further work could explore threshold values for muscle power and frailty status transitions over time.

Ethics approval

NHATS was approved by the John's Hopkins School of Health Institutional Review Board. As this paper uses publicly-available, de-identified data, no further Institutional Review Board approval was required.

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