Physical working capacity at fatigue threshold (PWC_{FT}) is associated with sarcopenia-related body composition and measures of functionality in older adults\(^{27}\)

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A B S T R A C T

The relationship between PWC_{FT} and common measures used to assess sarcopenia in older adults were examined. Fifty-eight older adults [age: 71.1 ± 6.2 years; body mass index (BMI): 28.0 ± 5.4 kg/m\(^2\)] completed the testing procedures. Sarcopenia-related body composition was measured by dual-energy X-ray absorptiometry and participants performed a discontinuous cycle ergometry test to determine PWC_{FT}. Functionality assessments included maximal isometric grip strength (GRIP) and sit-to-stand (STS) repetitions in 30 s. Muscle quality (MQ) was defined as GRIP relative to appendicular lean soft tissue (ALM), while skeletal muscle index (SMI) was defined as ALM/height\(^2\). Pearson correlations were used to examine the relationships among dependent variables. PWC_{FT} showed significant relationships with ALM (\(r = 0.57\), SMI (\(r = 0.47\), body fat percentage (BF\%) (\(r = -0.50\), GRIP (\(r = 0.49\), and STS (\(r = 0.44\). For follow-up analyses, study participants were categorized into low sarcopenia risk (\(n = 31\) or high sarcopenia risk (\(n = 27\) groups by SMI. Sarcopenia risk was associated with PWC_{FT} [odds ratio (OR): 1.051, 95% confidence interval (CI): 1.016–1.087] and STS (OR: 1.305, CI: 1.060–1.607), but not GRIP (OR: 1.098, CI: 0.989–1.218). Using receiver–operator characteristic curve analysis, both PWC_{FT} [area under the curve (AUC): 0.737, CI: 0.608–0.866, optimal cutoff: 37.5 W] and STS (AUC: 0.749, CI: 0.623–0.874, optimal cutoff: 12.5 repetitions) showed discriminative ability with regard to sarcopenia risk. The current data suggest that the neuromuscular fatigue threshold, as measured by PWC_{FT}, is related to measures of body composition and function in older adults.

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1. Introduction

Aging is a dynamic and progressive process characterized by a reduction in skeletal muscle mass, strength, and quality. Physical function in older adults is often evaluated with measures of muscular strength and body composition, such as MQ and SMI (Baumgartner et al., 1998; Janssen, Baumgartner, Ross, Rosenberg, & Roubenoff, 2004; Janssen, Heymsfield, & Ross, 2002; Lamoureux, Sparrow, Murphy, & Newton, 2002; Misic, Rosengren, Woods, & Evans, 2007). Low MQ and SMI have been associated with limitations when performing activities of daily living (ADLs) and an overall increased risk of physical disability (Goodpaster et al., 2006; Newman et al., 2003).

Most ADLs require repeated, sustained submaximal efforts, in which the capacity to perform physical work and delay fatigue may be particularly important to age-associated loss of functional performance (Katsiaras et al., 2005). deVries et al. (1987) suggested that impaired muscle function may be related to fatigue-induced deterioration of motor coordination. Thus, assessment of resistance to fatigue may be important to consider when evaluating the health status of older adults. However, measurement of fatigue is difficult in the older population, often requiring near maximal effort (i.e., VO\(_2\)max). With this in mind, deVries et al. (1987) developed the PWC\(_{FT}\), a submaximal exercise test to evaluate the capacity for physical work and the ability to delay fatigue.

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The PWC$_{FT}$ is non-invasive, submaximal, reliable, and sensitive to change in physical status (deVries et al., 1989). Several studies have reported significant increases in PWC$_{FT}$ following training (deVries et al., 1989) and/or nutritional supplementation (Stout et al., 2007, 2008) in older adults; however, the extent to which the PWC$_{FT}$ relates to measures of physical function in older adults remains to be investigated. Therefore, the purpose of this study was to identify the relationship between the PWC$_{FT}$ and other measures associated with sarcopenia-related body composition and physical function in older adults. Additionally, the effectiveness of the ability of select functional measures to discriminate between high and low sarcopenia risk was evaluated.

2. Methods

2.1. Subjects

Baseline values from 60 healthy, independently living men and women over the age of 60 years old, who participated in a separate interventional study (McCormack et al., 2013), were used for this investigation. Two subjects were excluded due to incomplete data; therefore, 58 subjects (25 men and 33 women) with a mean age of 71.1 ± 6.2 years (range 60–84) were included in the analysis (Table 1). All subjects completed a medical history questionnaire. No subjects reported major surgery within the last 6 months, history of asthma, heart or pulmonary disease, uncontrolled hypertension, and were not taking any medications that would interfere with exercise testing. All procedures were approved by the New England Institutional Review Board (IRB number 11-343). Prior to the beginning of the study, all subjects were advised of any possible risks before providing written informed consent.

2.2. Procedures

Upon arriving at the laboratory, subjects’ height and body mass were measured using a standard stadiometer and electronic scale (Health-o-Meter; Patient Weighing Scale, Model 500 KL, Pelstar, Alsip, IL, USA). Appendicular lean mass (ALM) and BF% were assessed using dual energy X-ray absorptiometry (DEXA) (Prodigy™, Lunar Corporation, Madison, WI, USA). Regions of interest for the arms (delineated from the thorax through the head of the humerus) and legs (delineated from the thorax through the neck of the femur), as estimated by the DEXA software, were summed to determine ALM. Skeletal muscle mass index (SMI) was calculated as ALM/height$^2$ as previously defined by Baumgartner et al. (1998). MQ was calculated with GRIP and DEXA-derived ALM [GRIP(㎏)/ALM(㎏)].

Subjects performed a discontinuous, cycle ergometry test on an electronically braked cycle ergometer to determine the PWC$_{FT}$, a handgrip dynamometry test (GRIP) to assess muscle strength, and a 30-s STS test to measure lower body functionality.

2.3. Electromyography (EMG) measurements

A bipolar (4.6 cm center-to-center) surface electrode (Quinton Quick-Prep silver-silver chloride) arrangement was placed over the right vastus lateralis muscle, at approximately 60% of the distance from the lateral portion of the patella on a line with the greater trochanter. The reference electrode was placed over the lateral epicondyle of the distal femur. Inter-electrode impedance was kept below 5000 $\Omega$ with abrasion of the skin beneath the electrodes. The raw EMG signals were pre-amplified using a differential amplifier (MP150 BIOPAC Systems, Inc., Santa Barbara, CA), sampled at 1000 Hz, bandpass filtered at 10–500 Hz (zero-phase shift fourth-order Butterworth), and stored on a personal computer (Dell Latitude E6530; Dell Inc., Round Rock, TX) for off-line analysis. The EMG signals were expressed as root mean square (rms) amplitude values ($\mu$Vrms) by software (AcqKnowledge v4.2, BIOPAC Systems, Inc., Santa Barbara, CA).

2.4. Determination of PWC$_{FT}$

Determination of PWC$_{FT}$ values was previously described by deVries et al. (1987) for the vastus lateralis. The initial work rate was set at 30 W for each test. The subjects pedaled at 50 revolutions per minute (rpm) for each 2-min stage of the test on an electronically braked cycle ergometer (Lode, Excalibur Sport, Groningen, Netherlands). A discontinuous protocol was adopted and each participant’s heart rate was allowed to return to within 10 beats per minute of resting values prior to completing subsequent 2-min stages. Toe clips were utilized for each subject. Following each stage, the raw EMG rms amplitude values were saved on a laptop computer and further analyzed with custom-written software (LabView, National Instruments Corporation, Austin, TX). If the stage did not produce a statistically significant, positive slope ($p < 0.05$) for the EMG rms amplitude versus time relationship, the resistance was increased 10–20 W until a statistically significant, positive slope was achieved or the subject reached 75% of their age-predicted maximal heart rate, or surpassed a rating of perceived exertion (RPE) of 13 (‘‘Somewhat Hard’’) on the Borg scale. Once a statistically significant, positive slope was reached, one final stage was performed at 5–10 W less than the resistance of the stage that produced the statistically significant, positive slope. The PWC$_{FT}$ was estimated to be the mean resistance of the highest non-statistically significant positive slope and the lowest statistically significant positive slope. In the event the subject did not have a statistically significant, positive slope during any stage of their PWC$_{FT}$, a regression analysis was performed utilizing slope and the corresponding workload (watts) as described by deVries, Moritani, Nagata, and Magnussen (1982). The y-intercept (watts) produced in this analysis was then used as the PWC$_{FT}$. The reliability of the PWC$_{FT}$ values for ten men and women similar to the cohort used in this study were analyzed using both calculation methods, resulting in intraclass correlation of 0.95 and standard error (SE) of measurement of 13.7 W.

2.5. Functional measures

During the GRIP, subjects were standing with the dynamometer (JAMAR, Sammons Preston Rolyan, Bolingbrook, IL) in their

Table 1

<table>
<thead>
<tr>
<th>Physical characteristics and functional measures for study participants.</th>
<th>All (n = 58)</th>
<th>Risk of sarcopenia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High (n = 27)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M = 11; W = 16</td>
</tr>
<tr>
<td><strong>Physical characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>71.1 ± 6.2</td>
<td>71.7 ± 6.1</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.65 ± 0.13</td>
<td>1.66 ± 0.10</td>
</tr>
<tr>
<td>Body mass (㎏)</td>
<td>76.7 ± 18.3</td>
<td>71.3 ± 16.9</td>
</tr>
<tr>
<td>BF%</td>
<td>36.2 ± 8.7</td>
<td>37.1 ± 7.7</td>
</tr>
<tr>
<td>BMI (㎏/m$^2$)</td>
<td>28.0 ± 5.5</td>
<td>25.7 ± 4.6</td>
</tr>
<tr>
<td>SMI (㎏/m$^2$)</td>
<td>7.23 ± 1.50</td>
<td>6.33 ± 1.14</td>
</tr>
<tr>
<td><strong>Functional measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWC$_{FT}$ (W)</td>
<td>52.0 ± 24.4</td>
<td>41.9 ± 19.2</td>
</tr>
<tr>
<td>STS (# in 30 s)</td>
<td>13.1 ± 4.5</td>
<td>11.4 ± 3.8</td>
</tr>
<tr>
<td>GRIP (㎏)</td>
<td>31.2 ± 12.5</td>
<td>28.8 ± 10.1</td>
</tr>
<tr>
<td>MQ</td>
<td>1.54 ± 0.39</td>
<td>1.63 ± 0.41</td>
</tr>
</tbody>
</table>

M: men; W: women.

*Significantly different between high and low sarcopenia risk groups.*
The dynamometer handle was adjusted so that the middle phalange of the third digit was comfortably perpendicular to the long axis of the handle. The arms were adducted with the dynamometer held at a 90° angle to their body. Subjects were instructed to squeeze the handle as hard as they could for 3–5 s. The average of three trials was recorded. Directly following the grip strength assessment, subjects completed a 30-s STS test which measured lower body functionality. Starting from a seated position with arms crossed and placed over the chest, the subject was instructed to rise to a fully standing position and return to a fully seated position as many times as possible in 30 s. Time began on the initial movement of the first repetition and was stopped at 30 s as indicated by a handheld stopwatch. STS values were recorded to the nearest whole number, for those repetitions that the subject made it to a complete standing position.

2.6. Statistical analysis

Statistical analyses were performed using SPSS v20 software (SPSS Inc., Chicago, IL). Data are shown as means and standard deviation (SD) for all variables. Pearson product moment correlations were used to examine the relationship between PWC_{FT}, and GRIP, STS, ALM, SMI, BF%, BMI, and MQ. Subjects were classified as high risk of sarcopenia (n = 27) by SMI < 6.29 kg/m² for women and < 8.51 kg/m² for men (Bouchard, Dionne, & Brochu, 2009); subjects with SMI values greater than these were classified as low risk (n = 31) (Table 1). Independent samples t-tests were used to determine differences between groups. Binary logistic regression was used to determine OR for the likelihood of sarcopenia risk as determined by measures of PWC_{FT}, STS, and GRIP. Receiver-operator characteristics (ROC) curve analysis was used to evaluate the ability of select functional measures to discriminate between low and high sarcopenia risk classification by a comparison of the area under the ROC curve with a value of 0.5 which can be interpreted as no discriminative ability. In order to establish estimated cutoff values from the ROC analysis, the functional measure result that yielded a balance between sensitivity and specificity, the minimum value from the equation: [(1 – sensitivity)² + (1 – specificity)²] was calculated (Akobeng, 2007). An alpha level of p < 0.05 and 95% CIs were used to determine statistical significance.

3. Results

Subject’s physical characteristics and functional measures are presented in Table 1. The measurement of PWC_{FT} showed significant positive correlations with ALM (r = 0.572, p < 0.01), SMI (r = 0.474, p < 0.01), GRIP (r = 0.485, p < 0.01), and STS (r = 0.440, p < 0.01). A significant negative relationship between PWC_{FT} and BF% was found (r = −0.498, p < 0.01). No significant relationships were shown between PWC_{FT} and MQ (r = 0.041, p = 0.76) or BMI (r = −0.038, p = 0.78). After accounting for BF%, partial correlations for ALM (r = 0.445, p < 0.01), SMI (r = 0.371, p < 0.01), GRIP (r = 0.344, p < 0.01), and STS (r = 0.305, p < 0.02) remained significant.

The mean values for body mass (p = 0.03), BMI (p < 0.01), SMI (p < 0.01), PWC_{FT} (p < 0.01), and STS (p < 0.01) were significantly different between the high and low sarcopenia risk groups (Table 1). No differences were found between groups for BF% (p = 0.48), GRIP (p = 0.19), or MQ (p = 0.12). The results from the logistic regression analyses, adjusted for age and gender, are reported in Table 2. A significant inverse relationship between sarcopenia risk and both PWC_{FT} and STS were found, with a ~5% decrease in the odds of sarcopenia classification for each 1 W increase in PWC_{FT} and a ~23% decrease in the odds of sarcopenia classification for each 1 repetition increase in STS performance. No significant relationship was found between sarcopenia risk and GRIP. According to the ROC curve analyses (Fig. 1A and B), PWC_{FT} and STS were able to discriminate between the high and low

![AUC: area under the curve, CI: confidence interval](image)

**Fig. 1.** Receiver–operator characteristic (ROC) curves for PWC_{FT} (A) and STS (B) tests between high and low sarcopenia risk groups.
and STS both possessed discriminative ability with regard to sarcopenia risk classification. The AUC for both functional measures were significantly different from 0.5 and the estimated cutoff values were 37.5 W for PWC_{CT} and 12.5 repetitions for STS.

4. Discussion

The results of this study suggest that PWC_{CT} is significantly related to sarcopenia-related body composition (SMI, ALM, and BF\%) and functional measures (STS and GRIP). According to follow-up analyses, the classification of sarcopenia risk may be significantly influenced by improvements in PWC_{CT} and STS. Additionally, both PWC_{CT} and STS were shown to possess acceptable discriminative ability with regard to sarcopenia risk classification in this sample of older adults.

The process of aging leads to atrophy of existing muscle fibers (Baumgartner, Stauber, McHugh, Koehler, & Garry, 1995). In addition, there appears to be a reduction in satellite cells that can compromise the ability to maintain growth in type II fibers (Verdijk et al., 2007). A decline in the ability to maintain muscle growth and repair through this reduction in type II fibers may eventually manifest itself in the form of sarcopenia. Furthermore, the process of motor unit remodeling may be compromised and apoptosis may be enhanced with aging (Deschenes, 2004; Dirks & Leeuwenburgh, 2005). While not directly measured in this study, these factors would result in decreased recruitment, ultimately altering the myoelectric properties of exercising muscle through a decrease in muscle activation. The relationships between PWC_{CT} values, body composition, and functionality, as well as the significant OR and discriminative ability, may be explained by some combination of these phenomena. Furthermore, with significant differences observed in both BMI and SMI between the sarcopenia risk groups in the current study, sarcopenic obesity may be an additional consideration.

While overall strength has been shown to decrease with age, lower body strength appears to be more affected than upper body strength (Candow and Chilibeck, 2005). And in agreement with the current findings, previous research has also reported no significant differences in GRIP between sarcopenic and non-sarcopenic groups (Chien, Kuo, & Wu, 2010; Landi et al., 2012). Furthermore, decreased SMI has been shown to be related to functional impairment, and physical disability in older adults with two- to three-fold greater risk of functional impairment and physical disability in older adults (Baumgartner et al., 1998; Chien et al., 2010; Janssen et al., 2002, 2004).

Research has been undertaken examining neuromuscular activation and its relationship with functionality in older adults. Clark and colleagues (Clark, Manini, Fielding, & Patton, 2013; Clark et al., 2011) have shown that neuromuscular impairment, measured as the rate of EMG rise, during leg press and walking can differentiate between older adults of varying levels of mobility function. Brach, Kriska, Newman, and VanSwearingen (2001) provided the foundation for this work when they demonstrated the utility of the rate of rise in quadriceps muscle activation during a chair stand task in elderly women and hypothesized that this measurement may be more sensitive to functional decline than other clinically accepted physical performance measures. Accordingly, the current results demonstrate STS, measured as the total number of chair stand repetitions completed in 30 s, may be used to distinguish between older individuals’ risk of being classified as sarcopenic. Similarly, Akune et al. (2013) noted a 5% increase in the odds of sarcopenia for every 1-s increase in the time taken to complete five chair stand tasks. Furthermore, chair rise time has shown to be significantly different between elderly men and women with and without sarcopenia as determined by the current diagnostic algorithm established by the European Working Group on Sarcopenia in Older People (Patel et al., 2013).

With regard to the ROC curve analysis in the current investigation, the optimal STS cutoff value of 12.5 repetitions in 30 s is consistent with below average scores (an indication of high risk for falls) as established for men (<12) and women (<11) by the Centers for Disease Prevention and Control (Rikli & Jones, 1999; Stevens & Phelan, 2013). Additionally, the AUC was similar (0.789), while the cutoff value was slightly lower (15 repetitions), to an ROC curve analysis examining the discriminative ability of the STS in differentiating between older adults with a history of falls (Cho, Bok, Kim, & Hwang, 2012).

While fatigue in the elderly is commonly assessed via self-report using validated questionnaires, the direct physiological measurement of fatigue thresholds is less prevalent. The direct physiological measurement may require maximal or near-maximal stress testing, along with medical clearance by a physician as recommended by the American College of Sports Medicine, or evaluators may rely on submaximal testing to estimate fatigue-related parameters (Pescatello & American College of Sports Medicine, 2014). Nonetheless, fatigue has shown to be a strong predictor of functional limitations and physical disability in older adults (Avlund, 2010). In the current study, the concept of physical working capacity, a measure of aerobic power, muscular efficiency and resistance to fatigue was evaluated using the PWC_{CT} during a submaximal cycle ergometry test.

When considering previous research in the elderly, PWC_{CT} has shown to improve in response to moderate intensity endurance training (Devries et al., 1989) as well as supplementation strategies aimed at improving phosphocreatine stores and muscle buffering capacity (Stout et al., 2007, 2008; Cadore et al., 2011), using EMG to assess muscle function, recently demonstrated significant relationships between neuromuscular economy, or the percentage of maximal voluntary muscle activation during submaximal cycling, and both strength and cardiorespiratory fitness in older adults. Therefore, the current findings appear to support previous research, which suggests that the direct measurement of neuromuscular activation during submaximal cycling is related to health and physical function in the elderly.

5. Conclusions

In summary, these data suggest that neuromuscular fatigue, as measured by PWC_{CT}, is related to measures of sarcopenia-related body composition and functionality in older adults. Therefore, neuromuscular fatigue may be an important factor to examine when assessing lower body function in older adults with high risk of sarcopenia classification and overall functionality in older men and women.

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Conflict of interest

The authors have no conflicts of interest to report.

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