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MUSCLE QUALITY, STRENGTH, AND LOWER EXTREMITY PHYSICAL PERFORMANCE IN THE BALTIMORE LONGITUDINAL STUDY OF AGING

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Abstract

Background: Muscle quality is defined as the force generated by each volumetric unit of muscle tissue. No consensus exists on an optimal measure of muscle quality, impeding comparison across studies and implementation in clinical settings. It is unknown whether muscle quality measures that rely on complex and expensive tests, such as isokinetic dynamometry and computerized tomography correlate with lower extremity performance (LEP) any better than measures derived from simpler and less expensive tests, such as grip strength (Grip) and appendicular lean mass (ALM) assessed by DXA. Additionally, whether muscle quality is more strongly associated with LEP than strength has not been fully tested.

Objectives: This study compares the concurrent validity of alternative measures of muscle quality and characterizes their relationship with LEP. We also whether muscle quality correlates more strongly with LEP than strength alone.

Design: Cross-sectional analysis.

Setting: Community.

Participants: 365 men and 345 women 65 years of age and older in the Baltimore Longitudinal Study of Aging.

Measures: Thigh cross-sectional area (TCSA), isokinetic and isometric knee extension strength (ID), BMI adjusted ALM (ALMBMI) from DXA, and Grip. Concurrent validity was assessed as the percent variance of different measures of LEP explained by each muscle quality measure. In addition, we compared LEP relationships between each measure of strength and its correspondent value of muscle quality. Confidence intervals for differences in percent variance were calculated by bootstrapping.

Results: Grip/ALMBMI explained as much variance as ID/TCSA across all LEP measures in women and most in men. Across all LEP measures, strength explained as much variance of LEP as muscle quality.

Conclusions: Grip/ALMBMI and ID/TCSA measures had similar correlations with LEP. Muscle quality did not outperform strength. Although evaluating muscle quality may be useful to assess age-related mechanisms of change in muscle strength, measures of strength alone may suffice to understand the relationship between muscle and LEP.

Keywords

Muscle quality; muscle strength; physical performance

Introduction

Muscle quality (MQ) can be conceptualized as the capacity to generate force relative to the mass/volume of contractile tissue (1–3). Declines in muscle strength with aging are not explained by declines in muscle mass; the concept of MQ was meant to describe this phenomenon (1, 2, 4–6). While strength alone quantifies the amount of force a muscle can generate, bigger muscles are not necessarily stronger. A smaller muscle may be more effective due to more contractile proteins, less fat infiltration, or other physiological properties that can alter the quality of the muscle (3, 6, 7). Therefore, MQ could be useful to comprehensively quantify physiological changes in skeletal muscle that occur with aging.

MQ has been assessed in multiple studies using different operational definitions (2, 3, 6, 8–14). In general, MQ is defined as the ratio of strength to mass, but it remains unclear which are the optimal methods to assess strength and mass. Previous studies used the ratio of quadriceps isokinetic peak torque (Quad) via isokinetic dynamometry (ID) to thigh muscle cross-sectional area (TCSA) assessed by computed tomography (CT) to characterize the effect of age and other risk factors on MQ (8, 12, 13, 15). The feasibility of this approach on a large scale is limited because CT and ID are expensive, time consuming to ascertain and difficult to process (10, 16, 17). ID allows for measurement of contractile force at constant velocity; however, it is more expensive than a hand dynamometer (HD) (18) and can be difficult for some older adults to complete due to lower back or leg pain and/or poor strength (13). In addition, whether ID/TCSA better captures the effect of muscle impairment on mobility compared to other measures of MQ is unknown. A simpler and less expensive method to assess MQ compared to ID/TCSA is the ratio of grip strength (Grip) via HD to appendicular lean mass (ALM) assessed via dual-energy X-ray absorptiometry (DXA). HD/DXA ratio has the advantage of requiring inexpensive instruments available in many research and clinical facilities and, therefore, can be easily assessed in most research or clinical situations.

This study aimed to compare the concurrent validity of alternative measures of MQ using lower extremity performance as the reference outcome. Lower extremity performance was used because it is widely considered the gold standard measure to assess the impact of muscle on mobility in older persons. We additionally tested the hypothesis that measures of MQ correlate with measures of lower extremity performance more strongly than strength.

Methods

Baltimore Longitudinal Study of Aging

The Baltimore Longitudinal Study of Aging (BLSA), which began in 1958, is the longest running study in the United States dedicated to studying human aging. Designed to assess normative aging, the BLSA is an observational study that continuously enrolls healthy adults aged 20 years and older. Follow-up study visits occur every 2 years for participants age 60–80, and annually for participants over 80 years of age. All enrolled participants gave informed consent. Further details on the study design have been previously reported (19).

Analytic Sample

This cross-sectional analysis included data from 365 men and 345 women aged 65 to 97 years visited between February 2011 and September 2015. All participants had measures of TCSA, ALM adjusted for body mass index (BMI) (ALMBMI), ID, and Grip.

Measures

Muscle Mass—Two measures of muscle mass were assessed, TCSA and ALM. TCSA was measured from 10mm CT scan of the mid-femur. Images were then filtered using the GEANIE BonAlyse software. TCSA was normalized for body height by dividing by height squared (TCSAht²). ALM was acquired from DXA whole body scans from the Prodigy Scanner using the Encore Software. ALM (kg) is the sum of the lean mass of the right and left arm and the right and left leg. ALM was normalized by dividing by BMI (ALMBMI).

Muscle Strength—Multiple ID muscle strength measures were acquired from a BioDex dynamometer. First, quadriceps peak torque (Quad) (Nm), an isokinetic strength measurement, was taken as the maximum of five trials of concentric knee extension strength at an angular velocity of 30°/s and 180°/s. Additionally, hamstring peak torque (Ham)(Nm) was taken as the maximum of five trials of concentric knee flexion strength at an angular velocity of 30°/s and 180°/s. Finally, isometric knee extension (Nm) was taken as the maximum of five trials at 120° and 140°. Grip was measured via a Jamar Hydraulic hand dynamometer, which registers maximum kg of force from three trials on each hand. The average of each trial was used for this analysis, consistent with previous studies (20).

Muscle Quality—In general, MQ was assessed as a ratio between a measure of strength and a measure of muscle mass in different combinations. The difficult and expensive MQ measures are each of the ID strength measures divided by TCSAht². The easy and relatively inexpensive MQ measure was Grip divided by ALMBMI.

Lower Extremity Physical Performance

Usual gait speed and rapid gait speed were each assessed on a 6m walking course. Participants were advised to walk at their usual pace or as fast as possible, respectively. The average gait speed is the average of two trials of participants walking at a usual pace, while rapid gait speed is the maximum of two trials where participants walked at their fastest pace. 400m walk time is derived from an endurance test, done as quickly as possible, conducted in an unobstructed corridor over a 20m long walking course.

The Short Physical Performance Battery (SPPB), an objective measure of lower-extremity function, comprises 4m usual gait speed, three standing balance tests, and time to complete five chair rises (Guralnik et al., 2000). Each of the three components of the SPPB are scored on a 0 to 4 scale, resulting in an overall SPPB score ranging from 0 to 12, with 12 indicating highest performance. The Health ABC Physical Performance Battery (HABCPPB) (Simonsick et al., 2001) is an extension of the SPPB aimed at avoiding a ceiling effect in a relatively high functioning population, including maintaining balance for longer time, a single leg stand and a narrow walk. Each component of the HABCPPB is scored on a continuous ratio scale ranging from 0 to 1, resulting in an overall HABCPPB score of 0 to 4, with 4 indicating highest performance.

Participants able to rise from a chair without assistance from chair arms completed repeated chair stands. Each chair stand pace is the ratio of number of chair stands completed to time (5s).

Analytic Strategy

Generalized linear models were used to predict average gait speed, rapid gait speed, 400m walk speed, SPPB, HABCPPB, and 5s chair stand pace. All analyses were stratified by sex and each model was adjusted for age. Concurrent validity was assessed as the percent variance (R^2) of the physical performance measures explained by each MQ measure. In addition, the amount of variance explained in each mobility outcome by different MQ measures were compared with their respective strength measure.

Bootstrapping was performed to compute confidence intervals for differences in percent variance explained by different models. The methods used for bootstrapping in SAS have been previously reported (21). A random seed was used for unrestricted random sampling of equal size as the original dataset. One thousand bootstrap samples were generated. From the bootstrap samples, generalized linear models were run with each physical performance measure as the dependent variable, and age and the MQ measures as the independent variables. The differences in R^2 values from each of the ID MQ variables and Grip/ALMBMI were calculated. The bootstrap samples were used to generate a 95% confidence interval for the differences in R^2 values. The same bootstrapping method was used to compare the difference in R^2 values from each of the MQ measures and its respective strength variable.

Results

Characteristics of the study sample are shown in Table 1. The average ages were 78.0 and 76.2 years for men and women, respectively. On average, participants tended to be slightly overweight and highly functional for their age (22).

Forest plots depicting the difference in R^2 values of each comparison difficult and expensive MQ measure to Grip/ALMBMI, and the respective 95% confidence intervals are shown in Figures 1 for women and men. The vertical line at the center of each plot, zero, represents no significant difference between the percent variance of a comparison MQ measure and Grip/ALMBMI. For each horizontal line, the center symbol is the difference in R^2 values (R^2 of

respective MQ measure minus R^2 Grip/ALMBMI), and the lines are the 95% confidence interval. The numerical values for percent variance in physical performance explained by each MQ measure is shown in Supplemental Table 1 for men and women separately. In women, Grip/ALMBMI and all ID/TCSA MQ measures explained comparable percent variances of the different physical performance outcomes. In men, in most instances, Grip/ALMBMI explained as much percent variance as ID/TCSA MQ measures for different performance outcomes. Exceptions were Quad180/TCSAht2, and Ham180/TCSAht2 that explained a higher percent variance in average gait speed and Quad180/TCSAht2 that explained a higher percent variance in rapid gait speed.

Figure 2 shows forest plots depicting the differences in R^2 values of each MQ measure to its respective strength measure (R^2 MQ minus R^2 strength), and the 95% confidence intervals for the differences. The construct of these forest plots is the same as previously described for Figure 1. The numerical percent variances of MQ versus strength for women and men are displayed in Supplemental Table 2. In women, there was no instance where MQ explained more variance than strength alone. Additionally, models fitted with MQ or strength measures yielded similar fit in term of R-square. In men, there were also no occasions where MQ produced a percent variance greater than strength alone. Strength alone, however, did produce significantly higher percent variance values compared to MQ in a few models: Ham180 when modeling rapid gait speed; Quad180, Ham30, and Ham180 when modeling rapid gait speed, and Quad180 when modeling chair stand 5s pace.

Discussion

For most of the physical performance outcomes, measures of MQ based on expensive, time consuming and not widely available tests, such as CT and lower extremity dynamometry were not better correlates of measures of mobility or lower extremity performance than measures of MQ based on handgrip strength and a DEXA derived measure of lean body mass. Exceptions, found only in men, were Quad180/TCSAht2 with average gait speed and rapid gait speed, and Ham30/TCSAht2 with average gait speed. Overall, ID/CT MQ measures comparably correlated with several physical performance measures as Grip/ALMBMI, including higher order, more sensitive performance measures. Additional measures of MQ were explored in this study, specifically ID/DXA, Isometric/CT, and HD/CT measures, however none performed as well as ID/CT or HD/DXA (data not shown). MQ measures of Grip with DXA acquired upper extremity lean mass and lower extremity lean mass were also assessed but produced R^2 values equivalent to Grip/ALMBMI, therefore they were not reported. These results suggest that Grip/ALMBMI is a valid if not superior substitute for more costly and burdensome measures of MQ.

To our knowledge, this is the only study to compare multiple measures of MQ as correlated with multiple physical performance measures. A previous comparison of grip strength, knee extension strength, and lower extremity muscle power found no statistical difference between measures in ability to identify those with gait speed less than 0.8 m/s (11).

When comparing MQ to muscle strength, all muscle strength measures explained as much, if not more, variance than their respective MQ measures. When assessing physical function,

strength alone may be the appropriate measure of muscular function. Other studies have also reported stronger associations between muscle strength vs MQ and physical performance measures. A comparison of multiple measures of CT acquired body composition and ID acquired muscle strength in the Age, Gene/Environment Susceptibility-Reykjavik (AGES-Reykjavik) Study found muscle strength to have the strongest associations with decline in gait speed over 5 years in men and women when compared to muscle mass, MQ, muscle attenuation, and intermuscular adipose tissue (14). Similarly, a comparison of muscle mass, muscle strength, and MQ in older men found muscle strength to have the strongest magnitude of association with functional limitation and physical disability and thus was the best clinical indicator of age-related muscle change(9). The current findings add to these previous studies by additionally assessing a MQ measure with muscle mass from CT and isokinetic quadricep strength. These results suggest that strength may suffice as a measure of muscle in a clinical setting.

A review assessing the optimal MQ measure suggested that muscle power, or the rate at which force is developed, should be used with muscle mass and muscle strength(1). They also concluded that energetic metabolism may add insight into the mechanisms that support MQ(1). It is possible that these additions may produce a MQ measure that correlates with physical performance better than strength alone.

MQ may provide a differential diagnosis of poor physical performance. Poor physical performance in the presence of normal MQ may be due to issues such as arthritis and pain, whereas poor physical performance with deficient MQ may be due to fat infiltration, decreased innervation, or decreased metabolism. Additionally, there are several factors that impact physical performance beyond strength and MQ, as evidenced by the modest R^2 values obtained in these analyses.

The BLSA allowed for the comparison of multiple MQ measures, including HD/DXA and ID/CT with respect to their association with several different physical performance outcomes of varying difficulty. A limitation of the BLSA is that it comprises a population that is healthy upon enrollment, therefore the results may not be generalizable to the broader older adult population. However, given that the muscular and physical function of many of the BLSA participants may be higher than that of the overall older adult population, it is possible that these results would be stronger in the general population. Even with the health of the BLSA population, 29% of those 65 and older who completed the handgrip assessment did not complete the BioDex, primarily due to pain or safety concerns. This proportion would probably be greater in the general population, highlighting the need for an easy and inexpensive clinical assessment of muscle for older adults of varying health statuses. An additional limitation is the lack of assessment of adiposity, particularly intramuscular fat, on MQ. Adiposity is associated with poorer MQ (14, 23); therefore, future research should assess whether the impact of adiposity on MQ differs by MQ measure.

From these results, it appears that Grip/ALMBMI is as good a MQ measure as those obtained using much more expensive and labor intensive machinery, such as Quad30/TCSAht². Further assessment will be needed to determine if these finding are maintained longitudinally. Grip/ALMBMI may not be as sensitive to detecting change in physical

performance; however, it could serve as an easily obtained initial screening tool for clinical application to identify older adults in need of more precise/extensive assessment of MQ. Furthermore, strength measures alone appear sufficient for assessing muscle function as it relates to physical performance.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Difference in R^2 in Muscle Quality Measures Compared to Grip/(ALM/BMI) in Women and Men

Quad30=quadricep peak torque at 30°/s, MQ=muscle quality, Quad180=quadricep peak torque at 180°/s, Ham30=hamstring peak torque at 30°/s, Ham180=hamstring peak torque at 180°/s, Isomet120=isometric knee extension at 120°/s, Isomet140=isometric knee extension at 140°/s. *All MQ measures are adjusted for Thigh cross-sectional area (kg) divided by height squared (m^2). † Difference in R^2 = Comparison MQ R^2 – Grip/ALMBMI R^2 .

Figure 2.

Difference in R^2 in Muscle Quality Measures Compared to Strength in Women and Men
 Grip=grip strength, MQ=muscle quality, Quad30=quadricep peak torque at 30°/s,
 Quad180=quadricep peak torque at 180°/s, Ham30=hamstring peak torque at 30°/s,
 Ham180=hamstring peak torque at 180°/s, Isomet120=isometric knee extension at 120°/s,
 Isomet140=isometric knee extension at 140°/s. *Grip MQ is adjusted for appendicular lean
 mass (kg) divided by BMI (kg/m²). All other MQ measures are adjusted for Thigh cross-

sectional area (kg) divided by height squared (m^2). † Difference in $R^2 = \text{MQ } R^2 - \text{Strength } R^2$.

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Table 1

Sample Characteristics

	Mean (SD) for Men	Mean (SD) for Women
Variables	n=365	n=345
Age, years	78.0 (7.4)	76.2 (7.5)
Body Mass Index, kg/m ²	27.11 (3.82)	26.55 (4.71)
Usual walking speed, m/s	1.09 (0.23)	1.05 (0.23)
Rapid gait speed, m/s	1.70 (0.44)	1.59 (0.36)
400 meter walk time, s	286 (64)	300 (68)
SPPB (0–12)	10.78 (2.16)	10.98 (1.90)
Health ABC PPB (0–4)	2.61 (0.79)	2.72 (0.67)
Chair Stand Pace 5s (# stands per second)	0.47 (0.20)	0.47 (0.17)

* SPPB=Short Physical Performance Battery, Health ABC PPB=The Health, Aging, and Body Composition Study Physical Performance Battery.