Muscle quality index improves with resistance exercise training in older adults


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ABSTRACT

Introduction: Sarcopenia is currently best described as an age-related decline in skeletal muscle mass and function. However, no consensus exists as to how to best quantify muscle function in older adults. The muscle quality index (MQI) was recently recommended as an ideal evidence-based assessment of functional status in older adults. Nevertheless, the usefulness of MQI to assess physical function is limited by whether it is reflective of muscle qualitative changes to an intervention. Thus, the purpose of this investigation was to determine whether MQI changes in response to resistance exercise training and detraining and how such changes correspond to other recommended measures of physical function proposed by suggested definitions of sarcopenia.

Methods: Twenty-five older adults (70.6 ± 6.1 y; BMI = 28.1 ± 5.4 kg · m⁻²) completed a 6-week resistance training program in a wait-list controlled, cross-over design. MQI was determined as power output from timed sit to stand (STS), body mass, and leg length. Gait speed, hand grip strength, get-up-and-go and lean body mass (LBM) were evaluated before and after exercise training and detraining. MQI and functional changes to training and detraining were evaluated with repeated measures ANOVA and clinical interpretations of magnitude based inferences.

Results: Short term resistance training significantly and clinically improved MQI (203.4 ± 64.31 to 244.3 ± 82.92 W), gait time (1.85 ± 0.36 to 1.66 ± 0.27 s) and sit to stand performance (13.21 ± 2.51 to 11.05 ± 1.58 s). Changes in LBM and hand grip strength were not significant or clinically meaningful. Detraining for 6-weeks did not result in significant changes in any measure from post-training performance.

1. Introduction

Sarcopenia, the age-related loss in skeletal muscle mass is closely related to mobility and functional impairments common with advanced age (Fiatarone et al., 1994; Foldvari et al., 2000; Janssen, 2006). The relative importance of muscle function for sarcopenic outcomes has led to more recent approaches to define sarcopenia incorporating muscle function into the diagnostic criteria (Cruz-Jentoft et al., 2010; Lauretani et al., 2003). However, the ability to diagnose sarcopenia and develop meaningful treatments has been complicated by the complexities of muscle function and differing rates of age-related changes. In particular, the rate that muscle strength declines is faster than the rate that muscle mass declines (Goodpaster et al., 2006). Similarly, the rate at which muscle power declines is even more rapid than the concomitant loss of muscle strength and mass (Frontera et al., 1991; Goodpaster et al., 2006; Hakkinen et al., 1996). Such temporal discrepancies reveal more intricate musculoskeletal changes associated with sarcopenia and aging than simply a loss of muscle tissue. Such changes are likely attributed to the quality of the muscle tissue (Goodpaster et al., 2001).

Skeletal muscle quality has been described in many ways ranging from muscle composition and density to muscle function per muscle mass to muscle’s metabolic processes (Barbat-Artigas et al., 2012). Muscle quality is often assessed indirectly as a relative performance indicator defined as muscle strength per muscle mass (Moritani and deVries, 1979). When defined in this way, muscle quality declines are associated with advanced age (Lindle et al., 1997; Lynch et al., 1999). While aging attenuates muscle’s hypertrophic responses to resistance training (Welle et al., 1996), it does not appear to impair muscle quality adaptations to resistance exercise in older adults (Welle et al., 1996). Hence, muscle quality may present a meaningful, informative, and sensitive target to monitor sarcopenia status and treatment efficacy, beyond routine measures of muscle mass. In particular, a simple muscle qualitative assessment that can be conducted feasibly during routine clinical examinations may have the broadest impact for assessment and evaluation. Functional measures, by way of muscle quality estimation, may allow for clinicians to account for the interaction between declining muscularity and intramuscular fat infiltration which may be
misinterpreted or neglected for by standard sarcopenic evaluation involving only muscle mass in aging adults.

Recently, Barbat-Artigas et al. (2012) reviewed and recommended the muscle quality index (MQI) as a “clinical screening tool to detect individuals at risk of physical incapacities based on muscle quality.” The MQI calculates muscle power from anthropometric measures (e.g., leg length and body mass) and timed chair rises (Takai et al., 2009). The MQI assessment is particularly informative in comparison to other measures because it evaluates specific lower extremity function that is related to ambulation, as opposed to non-muscle group specific measures of handgrip strength. In addition, the MQI is a more complete index of muscle quality than relative strength since it incorporates the velocity at which muscle shortens (i.e., muscle power), which is reflective of the neuromuscular component. Furthermore, the assessment is clinically relevant, since it is calculated from the common sit to stand test. Utilizing the familiar timed sit to stand test, the assessment is appropriate for older persons who may have physical limitations, safety concerns and/or sarcopenia. Moreover, prior research has shown that the ability to rise from a chair is related to functional independence in older adults (Corrigan and Bohannon, 2001). MQI can be distinguished from the common sit to stand test as, as it incorporates anthropometric measures of body mass and leg length to which have previously been shown to alter the relationship between chair rise performance and leg strength (Takai et al., 2009). The MQI has been shown to be strongly correlated to the cross-sectional area of the knee extensors ($r = 0.801$) and force of the knee extensors ($r = 0.730$) in older adults, while timed sit to stand was not (Takai et al., 2009).

While the MQI has been recommended as the “best clinical measure to assess muscle power” (Barbat-Artigas et al., 2012), no proposed definitions of sarcopenia have incorporated the potentially more sensitive muscle quality measure of muscle power into the proposed criteria. For muscle quality to become an appropriate target of treatment strategies for sarcopenia, we need to generate a better understanding of the adaptability of aspects of muscle quality at the clinical level. Hence, the purpose of the present investigation was to examine if and how MQI changes in response to a resistance training and detraining intervention in older adults and how such changes compare to other measures of physical function commonly measured in older adults.

2. Materials and methods

2.1. Experimental approach to the problem

To determine the effects of resistance training and detraining on muscle quality index (MQI), older adult volunteers completed two phases of the experimental protocol, both of which included a 6-week resistance training program, in a wait-list controlled, cross-over design (Fig. 1). Volunteers were randomized into exercise group 1 or exercise group 2. Exercise group 1 completed 6-weeks of resistance training in Phase 1 and 6-weeks of detraining (no resistance training) in Phase 2. Exercise group 2 completed a 6-week control period of no resistance exercise intervention where they were instructed to maintain their normal daily activities in Phase 1 followed by 6-weeks of resistance exercise training in Phase 2. All participants were tested at 3 time points separated by 6-weeks of resistance exercise training either preceded by detraining (Phase 1) or preceded by a control condition (Phase 2).

MQI and functional measures were determined before and after Phase 1 and Phase 2 at weeks 0, 6, and 12. Reliability intra-class correlation coefficients (ICC) and standard error of measurements (SEM) were computed from 11 participants in the control group.

2.2. Participants

Twenty-five older adults volunteered for the study (70.5 ± 6.2 y; 168.4 ± 9.4 cm; 81.4 ± 19.0 kg). Participants were recruited from a variety of sources including word of mouth, flyers, and informational presentations. Participants were required to be over age 60 y and physically cleared for exercise participation according to a health history questionnaire or physicians clearance. Physician clearance was required for any participant over age 70 y or any potentially positive risk factor as indicated on the medical history questionnaire. Individuals classified as “high risk” for exercise by having a cardiovascular, pulmonary, or metabolic disease, or one or more cardiovascular signs and symptoms were excluded from participation. Participants were randomly assigned to either group 1 ($n = 13$) or group 2 ($n = 12$). Participants were recruited so that an equal number of men and women was randomized to each group. During both phases of the protocol, all participants were instructed to follow their normal diets. Two women completed pre-testing but did not complete all time points due to personal reasons not associated with the study. One man chose not to complete the week 12 DEXA test. Thus, 23 individuals were included in the final analysis, with $n = 22$ for the body composition analysis. Participants were informed of study procedures, and provided written informed consent prior to enrolling in the study. All study procedures were reviewed and approved by the Institutional Review Board for the Protection of Human Subjects at the University of Central Florida.

2.3. Measures

2.3.1. Anthropometrics

Body mass and stature were measured following standardized anthropometric protocols on a digital scale and an upright stadiometer during each testing occasion. Body mass index was calculated from these measures as kg · m$^{-2}$.

2.3.2. Dual-energy X-ray absorptiometry

Total body composition was evaluated using dual energy X-ray absorptiometry (DEXA) technologies obtained on a whole body scan. All DEXA scans were ordered by a licensed physician in the state of Florida and were performed in the Body Composition Laboratory by a technician licensed in the state of Florida.

![Fig. 1. Study design.](image-url)
2.3.6. Timed sit to stand

The timed sit to stand task was used to determine participants’ ability to transfer from a seated position to standing and maintain balance. A stopwatch was used to record the time it took for the participant to sit for 5 s, rise to a standing position, and walk 3 m. The participant was allowed to use any usual walking aids. Spotters were in place to ensure that participants were challenged to the specific challenge of each exercise. Training intensity was set to a load resistance that was appropriate for each participant. Resistance was adjusted to allow for adequate progressions of all of the major muscle groups. 

2.3.7. Muscle quality index

Muscle quality index (MQI) was measured according to methods devised by Takai et al. (Takai et al., 2009) (ICC3,1 = 0.907, SEM = 21.91 W). MQI uses timed sit to stand, individual body mass, and leg length to calculate a power index reported in watts (W). According to the following equation (Takai et al., 2009):

\[
MQI = \left(\frac{\text{leg length} \times 0.4}{\text{body mass} \times \text{gravity} \times 10}\right) \times \text{Time sit-stand}
\]

where leg length was defined as the distance (in meters) from the great trochanter of the femur to the malleolus lateralis as determined from the full body scan on scan on the DEXA. The coefficient of 0.4 (m) represents the height of the standard chair used for the chair rise test, the force of gravity was represented by 9.81 m s⁻², and 10 represents a constant from the original equation (Takai et al., 2009). The validity and reliability of the MQI measure have been previously reported (Takai et al., 2009).

2.3.8. Strength training protocol

Before beginning the resistance training program, all participants completed two familiarization sessions where proper form and technique of each exercise were learned and the starting load resistance for each exercise was assigned. Training intensity was set to a load corresponding to perceived moderate intensity. The OMNI scale of perceived exertion was used to assess perceived difficulty (0 = sitting or no exertion to 10 = all-out effort). The program consisted of two workouts per week with sessions lasting 1 to 1.5 h. Each workout was separated by at least 48 h to allow for adequate recovery. The training program consisted of an individualized, periodized, full-body program including exercises of varying progressions of all of the major muscle groups. Exercises included machine-based exercises (leg extensions, leg curls, seated rows, and lat pull-downs), body weight exercises (squats, split squats, abdominals, calf raises, and modified stiff-legged dead-lifts) and free weight exercises (biceps curls, chest presses, shoulder presses, tricesp extensions and progressions for body weight exercises). Acute program variables varied progressively throughout the 6-weeks, but generally consisted of three (3) sets of 8 to 15 repetitions of 7 to 8 exercises at moderate intensity (perceived exertion of 5–6 on a 10 point scale). Resistance was adjusted to allow for the completion of the designated repetition range and to ensure that participants were challenged to the specified perceived exertion rating. Each workout session began with a standardized dynamic warm-up consisting of body weight squats, high knee walking, and limb rotations and terminated with an appropriate cool down. The exercise program followed the recommended guidelines for older adults by the American College of Sports Medicine and the National Strength and Conditioning Association and was supervised by National Strength and Conditioning Association’s Certified Strength and Conditioning Specialists, who were also certified in cardio-pulmonary resuscitation (CPR) and automatic external defibrillation (AED).

2.3.9. Control period protocol

During the 6-week control (Phase 1) or detraining period (Phase 2), participants completed all testing procedures and were instructed to maintain their normal level of daily physical activity throughout the study period. Participants assigned to exercise group 2 were told that they were on the “wait-list” for the exercise program and were able to enroll in the exercise program following mid-testing.

2.4. Analysis

Data were analyzed using separate repeated measures ANOVA to evaluate dependent variable changes by intervention and group for Phase 1 and Phase 2. In the event of a significant F score, a post-hoc paired t-test was used to determine pairwise differences. Independent sample t-tests were run to evaluate baseline differences between the
In order to compare the relative changes of each functional outcome, the combined values of the training periods for each group (n = 23) were evaluated using a magnitude-based inference approach. Changes in functional measures were analyzed using magnitude based inferences, calculated from 90% confidence intervals, as previously described (Hopkins et al., 2009). Change scores reflecting improvement or reduction in functionality were analyzed using the p value from dependent t-tests to determine a mechanistic inference. Qualitative inferences were based upon the chances that the true magnitude of the effect at post-training was substantially improved or reduced compared to pre-training values, and was assessed as: <1% almost certainly reduced, 1–5% very likely reduced, 5–25% likely reduced, 25–75% possibly improved, 75–95% likely improved, 95–99% very likely improved and >99% almost certainly improved. If there was a greater than 5% chance that the true value was both improved and reduced, the effect was considered mechanistically unclear. The smallest non-trivial change or smallest worthwhile change, was set at 20% of the pre-training standard deviation. Significance for this study was set a priori at p ≤ 0.10. A significance of p ≤ 0.10 was elected to reduce the likelihood of accepting the null hypothesis and missing detection of an important change in this first study to explore changes in MQI. Data are presented as mean ± SD unless otherwise stated.

3. Results

The baseline descriptive characteristics and physical function measures of the study participants are shown in Tables 1 and 2, respectively. Groups were similar in age, anthropometrics and physical function at baseline, with the exception of get-up and go time where Group 2 was faster (p = 0.042).

3.1. Phase 1 (training vs. control)

Significant interactions between exercise training and control were observed for MQI (p = 0.062), gait speed (p = 0.035), and sit to stand time (p = 0.042) (Table 2). MQI increased by 22% (199.06 to 242.88 W), gait speed improved by 15% (1.92 to 1.64 s), and sit to stand time improved by 18% (14.19 to 11.57 s) from pre to post-testing after 6-weeks of resistance exercise in group 1. No intervention by time interactions were observed for hand grip strength, get up and go or LBM in phase 1 (p > 0.10). No significant changes in functional measures were observed in the control group (group 2) during phase 1.

3.2. Phase 2 (training vs. de training)

Significant interactions between training and de-training were observed for MQI (p = 0.001), sit to stand (p = 0.000), and gait speed (p = 0.076) in phase 2. MQI increased by 18% (208.18 to 244.99 W), sit to stand time improved by 14% (12.14 to 10.48 s), and gait speed improved by 5% (1.77 to 1.68 s) from pre to post-testing after 6-weeks of resistance exercise in group 2. No intervention by time interactions were observed for hand grip strength, get up and go or LBM in phase 2 (p > 0.10). Post-hoc pairwise comparisons revealed that six weeks of detraining did not result in significant losses (p > 0.10) in improvements that were attained during the training regimen (Table 2). Performance measures changed by 1.0 to 4.8% between post-training (week 6) and detraining (week 12) in group 1.

3.3. Clinical changes in functional measures

Magnitude-based inference analyses of changes in functional measures for the combined training groups (n = 23) are presented in Fig. 2 and Table 3. Clinical interpretations based on smallest worthwhile changes limits reveal that MQI and STS "most likely improved" and GUG and gait speed, "very likely improved," while changes in LBM and hand grip strength were "unclear" or "trivial" in response to resistance exercise training. The likelihood of improvement in MQI and STS was >99% and GUG and gait speed was >95%. Changes in grip strength and LBM were primarily trivial (74.9 to 79.9%).

4. Discussion

In order to provide evidence-based support for the previously recommended muscle quality index, we primarily sought to determine whether MQI changes in response to resistance exercise training and detraining. Secondary, we sought to determine how changes in MQI compared to other recommended measures of physical function (sit to stand, gait speed, and grip strength) and muscul arity (lean body mass) suggested by the proposed definitions of sarcopenia. Our results show that MQI increases with resistance exercise training in older adults to a greater magnitude and presents higher reliability than other functional measures. Additionally, improvements were maintained during the detraining period. These findings may have future clinical implications for quantifying muscle function as a symptom of sarcopenia during routine physical examinations.

Our main results show that muscle quality index (MQI), a clinical assessment of physical function, increases with 6-weeks of resistance exercise in older adults. This is the first investigation to our knowledge to evaluate change in MQI to any intervention. As MQI measures the force generating capacity of the knee extensor muscles (Takai et al., 2009), we had expected to see improvements as a result of the training program. The muscle groups responsible for leg extension were trained with modified squat, split squat, and machine leg extension exercises during the full body progressive exercise training regimen. As we previously reported, laboratory-based measures of leg extension strength and relative strength significantly increased 32% and 31%, respectively, from the implemented training regimen (Scanlon et al., 2013). The sensitivity and reliability of the MQI to detect improvements, as shown in the present study, highlight the potential clinical utility of this new measure. As an elaborative clinical measure of the more common and simple measure of timed sit to stand, MQI also incorporates the anthropometric measures of body mass and leg length. Previously, body size has been shown to alter the relationship between chair rise performance and leg strength (Takai et al., 2009). MQI incorporates body dimensions in its computation; therefore, it may be a more informative measure despite the diversity of body size observed in human populations. Although, no significant body mass or composition changes were detected in the present study, inclusion of anthropometrics makes MQI a comparative relative measure among individuals of varying body sizes, especially men and women. While the present study included both men and women to maximize the potential generalizability of the findings and was not statistically powered to run analyses by gender, gender is an important consideration in interpreting responses to interventions for sarcopenia.

The observed magnitude of change in MQI was greater than other measures of physical function (e.g. gait speed, grip strength, timed chair rise, get-up and go) or muscle status (e.g. lean body mass). As it is ideal for functional measures of muscular status to be both specific to measure relevant characteristics and sensitive to respond to directed intervention, our preliminary results support the MQI measure to be further evaluated. While measures of gait speed, grip strength, and
Table 2
Changes in measures of physical function observed from during Phase 1 and Phase 2.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle quality index (W)</td>
<td>199.06</td>
<td>242.88</td>
<td>245.58</td>
</tr>
<tr>
<td>Group 1</td>
<td>190.06</td>
<td>± 69.14</td>
<td>± 97.13*</td>
</tr>
<tr>
<td>Group 2</td>
<td>190.59</td>
<td>± 80.71</td>
<td>± 61.58*</td>
</tr>
<tr>
<td>Hand grip strength (kg)</td>
<td>36.25</td>
<td>208.18</td>
<td>244.99</td>
</tr>
<tr>
<td>Group 1</td>
<td>32.82</td>
<td>± 10.94</td>
<td>± 13.58*</td>
</tr>
<tr>
<td>Group 2</td>
<td>13.75</td>
<td>± 14.17</td>
<td>± 16.48</td>
</tr>
<tr>
<td>Gait time (s)</td>
<td>1.92</td>
<td>1.64</td>
<td>1.70</td>
</tr>
<tr>
<td>Group 1</td>
<td>1.75</td>
<td>± 0.44</td>
<td>± 0.28*</td>
</tr>
<tr>
<td>Group 2</td>
<td>1.75</td>
<td>± 0.41</td>
<td>± 0.24*</td>
</tr>
<tr>
<td>Sit-to-stand (s)</td>
<td>14.19</td>
<td>11.57</td>
<td>11.39</td>
</tr>
<tr>
<td>Group 1</td>
<td>12.92</td>
<td>± 2.17</td>
<td>± 1.65*</td>
</tr>
<tr>
<td>Group 2</td>
<td>8.67</td>
<td>± 2.57*</td>
<td>± 1.61*</td>
</tr>
<tr>
<td>Get-up and go (s)</td>
<td>8.14</td>
<td>7.52</td>
<td>7.16</td>
</tr>
<tr>
<td>Group 1</td>
<td>8.41</td>
<td>± 0.86</td>
<td>± 1.28*</td>
</tr>
<tr>
<td>Group 2</td>
<td>12.92</td>
<td>± 10.67</td>
<td>± 0.94</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>47.70</td>
<td>47.92</td>
<td>49.19</td>
</tr>
<tr>
<td>Group 1</td>
<td>49.58</td>
<td>± 13.48</td>
<td>± 10.51</td>
</tr>
<tr>
<td>Group 2</td>
<td>49.58</td>
<td>± 13.48</td>
<td>± 13.23</td>
</tr>
</tbody>
</table>

Note for timed tests of STS, Gait, and GUG a reduction in time (s) corresponds to improved performance.

*p = 0.042 between groups at baseline.
*p < 0.10 from previous time-point.
*p < 0.10 for interaction between groups at specified time-point.

Table 3
Changes in functional measures pre- and post-training.

<table>
<thead>
<tr>
<th>Measure</th>
<th>n</th>
<th>Pre</th>
<th>Post</th>
<th>p</th>
<th>Difference</th>
<th>Pos</th>
<th>Triv</th>
<th>Neg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle quality index (W)</td>
<td>23</td>
<td>203.43</td>
<td>244.25</td>
<td>0.000</td>
<td>41 ± 19</td>
<td>99.7</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Hand grip strength (kg)</td>
<td>23</td>
<td>35.26</td>
<td>37.43</td>
<td>0.010</td>
<td>2.2 ± 1.6</td>
<td>25.1</td>
<td>74.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Sit-to-stand (s)</td>
<td>23</td>
<td>13.21</td>
<td>11.05</td>
<td>0.000</td>
<td>−2.2 ± 0.93</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Gait time (s)</td>
<td>23</td>
<td>1.85</td>
<td>1.66</td>
<td>0.005</td>
<td>−0.19 ± 0.13</td>
<td>0.0</td>
<td>4.9</td>
<td>95.1</td>
</tr>
<tr>
<td>Get-up and go (s)</td>
<td>23</td>
<td>8.25</td>
<td>7.33</td>
<td>0.002</td>
<td>−0.92 ± 0.57</td>
<td>0.0</td>
<td>3.7</td>
<td>96.3</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>23</td>
<td>48.4</td>
<td>48.7</td>
<td>0.869</td>
<td>0.3 ± 3.6</td>
<td>12.8</td>
<td>79.9</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Note for timed tests of STS, Gait, and GUG a reduction in time (s) corresponds to improved performance.

*Percent

n = sample size; Pre = pre-training; Post = post-training; p = significance; Pre and Post values presented as mean ± SD. Difference values presented as mean ± 90% confidence intervals.
Pos = % positive change; Triv = % trivial change; Neg = % negative change. 1Note for timed tests of STS, Gait, and GUG a reduction in time (s) corresponds to improved performance.

5. Conclusion

In conclusion, MQI significantly changes in response to short term resistance exercise training to a clinically meaningful magnitude in older adults. Improvements in MQI exceeded those of other measures of muscular function and status. Additionally, because MQI is based on the timed sit to stand test, it has high potential clinical applicability. Thus, the feasibility, sensitivity and reliability of MQI assessment make it an informative and potentially useful tool for clinical and interventional assessments of the functional status associated with sarcopenia. Future studies should further evaluate this measure with others in additional interventional trials. Interestingly, no performance decrements were observed in 6-weeks of detraining in older adults. Thus, functional improvements attained from short term resistance training can potentially be sustained for up to 6-weeks following cessation. Future studies are needed to determine if the results are due to residual adaptations or increased functional capacities translated to daily living.

Conflict of interest

Authors have no financial or personal conflicts of interest to report which may be perceived to influence the results.

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References


