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Original Study

# Muscle Quantity Is Not Synonymous With Muscle Quality

Sébastien Barbat-Artigas PhD(c)[a,b,c], Yves Rolland MD, PhD[d,e], Bruno Vellas MD, PhD[d,e], Mylène Aubertin-Leheudre PhD[b,c,f,*]

[a] Département de Biologie, Université du Québec à Montréal, Montréal, Canada
[b] Groupe de Recherche en Activité Physique Adaptée, Université du Québec à Montréal, Montréal, Canada
[c] Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal, Montréal, Canada
[d] Service de Médecine interne et de Gérontologie Clinique, Gérontopôle de Toulouse, Hôpital La Grave-Casselardit, Toulouse, France
[e] Unité Inserm 1027, Faculté de Médecine de Toulouse, Toulouse, France
[f] Département de Kinanthropologie, Université du Québec à Montréal, Montréal, Canada

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A B S T R A C T

*Background:* Greater muscle mass can generally produce greater muscle strength. However, whether higher muscle mass is associated with higher muscle quality (muscle strength relative to muscle mass) remains unknown. Furthermore, the nature of this relationship, and how their interaction determines the presence of functional impairments are unknown. This article aims to address these issues.
*Methods:* Secondary data analysis including 1219 women aged 75 years and older of the Toulouse ÉPI-Demiologie de l'OSteoporose cohort study. Body composition (dual energy X-ray absorptiometry), handgrip, and knee extension strength were assessed. Physical function was measured using the chair stand test as well as the usual and fast gait speed tests. Participants were also asked if they experienced any difficulty in performing functional tasks.
*Results:* Upper- and lower-body muscle quality ($r = -0.42$, $P < .001$ and $r = -0.16$, $P < .001$, respectively) were significantly and negatively correlated with appendicular skeletal muscle mass index (ASMI). Independently of ASMI, individuals with high muscle quality had low risks of functional impairments (odds ratio $<0.74$), whereas individuals with high ASMI but low muscle quality had high risks of impairments (odds ratio $>1.27$).
*Conclusions:* This inverse relationship between muscle mass and quality implies that sarcopenic individuals have better muscle quality than nonsarcopenic individuals. Results also suggest that high muscle quality may compensate for low ASMI with respect to functional impairments. Physical activity may potentially be involved in this relationship.


The rationale for encouraging an increase in muscle mass in older people is partly based on the belief that low muscle mass is associated with low muscle strength and poor physical performances.[1] This assumption is largely supported by epidemiologic cohorts demonstrating that muscle mass is positively associated with muscle strength,[2–4] and that low muscle strength is associated with increased risk of impairments.[5,6] Inversely, it is assumed that individuals with greater muscle mass are, therefore, stronger, so that they are not supposed to have physical impairments.

However, although muscle mass may be a major contributor to the production of strength, this relationship remains low to moderate in magnitude. Hughes et al[7] even reported over a 10-year follow-up that less than 5% of changes in muscle strength were attributable to changes in muscle size. It is likely that neural factors partly contribute to the dissociation between muscle mass and muscle function,[8,9] but most of this dissociation may possibly be explained by muscle-specific factors (other than muscle quantity) and variations in its intrinsic capacity to generate strength, that is to say its quality. Although muscle quality is usually simply calculated as the ratio of muscle strength per unit of muscle quantity, it actually reflects several muscle characteristics such as its architecture,[10] its composition in terms of fiber typing or its lipid content,[11] as well as the ability of connective tissues to transmit the strength produced by contractile tissues,[12] all of which require sophisticated tools and techniques that are not necessarily available, especially in large-scale studies.

Variations in 1 or more of these characteristics and, thus, in muscle quality, may explain why individuals with similar muscle mass do not

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* Address correspondence to Mylène Aubertin-Leheudre, PhD, Départment de kinanthropologie, Université du Québec à Montréal, Case postale 8888, succursale Centre-ville, Montreal, Quebec, Canada, H3C 3P8.
*E-mail address:* aubertin-leheudre.mylene@uqam.ca (M. Aubertin-Leheudre).

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necessarily have similar muscle strength and, consequently, do not have similar risks of having impairments. Muscle strength is a major (if not the best) determinant of functional capacity; variations in muscle quality may also explain why muscle mass is, by comparison, a relatively weak indicator of functional capacity.[13]

On the one hand, greater muscle mass can generally produce greater muscle strength. On the other hand, despite divergent results,[14] there is accumulating evidence that muscle quality is associated with functional capacity in healthy[13,15–17] and diabetic[18] older adults. Muscle quality has also been reported to predict mortality in healthy[19] and diabetics[20] elderly. The combination of these 2 observations suggests that muscle mass may be associated with muscle quality. Apart from aging[16,21] and physical intervention,[22] previous research identified factors, such as fat mass,[11,21] that may influence muscle quality. However, there is little evidence on the relationship between muscle quality and muscle mass itself.[23] Furthermore, the nature of this relationship, and how their interaction determines the presence of functional impairments are unknown.

Consequently, the first objective of the present analyses was to investigate the relationship between muscle mass and quality. We then examined whether low muscle mass and low muscle quality, alone or in combination, were associated with functional impairments.

## Methods

### *Study Population*

Data for the present study were obtained from the EPIDemiologie de l'OSteoporose (EPIDOS) study. EPIDOS is a prospective cohort study carried out of 5 French cities (Amiens, Lyon, Montpellier, Paris, and Toulouse) whose primary purpose was to assess hip fracture risk factors in a healthy community-dwelling population of elderly women. The sampling and data collection procedures were previously described in detail.[24] Briefly, all women aged 75 years or older and living in 1 of the 5 cities were invited to participate by mail through the use of population-based listings, such as voter-registration or health-insurance membership rolls or conferences in associations such as "Third-Age University" and advertisements. To be included, women had to (1) live in the community, (2) have no previous history of hip fracture or hip replacement, and (3) be able to understand and answer the questionnaire. All participants gave written informed consent. The program was approved by the Toulouse Hospital ethics committee. The baseline examination was performed in a clinical research center by a trained geriatric nurse. From the 1462 women of the Toulouse EPIDOS cohort, 243 were excluded from the analyses because they had no body composition or muscle strength baseline measurements. The present analyses were limited to the baseline data of the 1219 remaining participants.

### *Demographic and Health Assessment*

A physical examination and health status questionnaire were used to record comorbid conditions (hypertension, diabetes, cancer, stroke, Parkinson disease, depression, or other disease). Cognitive impairment was assessed with Pfeiffer test,[25] and a test score <8 was considered low. The highest level of education (illiterate, elementary, primary school, high school, or postgraduate school) was noted. Participants also self-reported in a structured questionnaire whether they regularly practiced recreational physical activities such as walking, gymnastics, cycling, swimming, or gardening. The type, frequency, and duration of each leisure physical activity were recorded. Women were considered physically active if they practiced at least 1 recreational physical activity for ≥1 hour/week for the past month or more. Monthly income was divided into 4 groups: <450€, 450–900€, 900–1300€, and >1300€.

### *Anthropometric Measurement and Body Composition Assessment*

Anthropometric measurements (weight and height) were performed by using standardized techniques.[26] Dual energy X-ray absorptiometry (DXA; QDR 4500 W Hologic, Waltham, MA) was used to measure muscle mass. DXA measurements were performed by a trained technician, and the DXA machine was regularly calibrated.

Skeletal muscle mass was based on appendicular skeletal muscle mass (ASM) measures. ASM corresponds to the sum of the 2 upper and lower limb muscle masses in kilogram. ASM was then normalized for height to create an ASM index (ASMI = ASM/height$^2$) and reported in tertiles.

### *Muscle Strength Measurement*

#### *Handgrip strength*

Handgrip strength (HGS) was measured for the dominant hand with a hydraulic hand dynamometer (Martin Vigorimeter; Medizin Tecnik, Tuttlingen, Germany). The size of the grip was adjusted so that the participant felt comfortable. The participant stood upright with the arm vertical and the dynamometer close to the body. The maximal peak pressure expressed in kiloPascal (kPa) was recorded for a set of 3 contractions.

#### *Knee extension strength*

Knee extension strength (KES) was assessed using a strain gauge system attached to a chair upon which subjects were seated with both hips and knees flexed at 90° angle. The leg to be tested was fixed to the lever arm on an analog strain gauge to measure strength. The highest of 3 maximum voluntary contractions expressed in kPa was recorded for the dominant leg.

### *Muscle Quality Calculation*

Upper body muscle quality (UB-MQ) was calculated by dividing handgrip strength by upper limbs muscle mass measured by DXA (kPa/kg). Lower body muscle quality (LB-MQ) was calculated by dividing knee extension strength by lower limbs muscle mass measured by DXA (kPa/kg). This definition of muscle quality is commonly used in large-scale studies by us[27] and others[19,21] because of its convenience. However, because it also involves nonmuscular aspects of force generation, such as neural activation,[9] it slightly differs from definitions used in studies of smaller scale or in animal studies where more accurate measurements can be performed.[28]

### *Creation of Subgroups According to Muscular Profile*

Because we previously observed that in this cohort lower body muscle characteristics were better associated with functional capacity scores than upper body muscle characteristics,[27] lower body muscle quality, rather than upper body muscle quality, was chosen to classify women. Thus, the 1219 women were classified by tertiles (low [L], medium [M], and high [H]) for ASMI and LB-MQ. Tertiles cutpoints for ASMI were ≤.97 kg/m$^2$ (L; n = 406), 5.98–6.62 kg/m$^2$ (M; n = 407) and ≥6.63 kg/m$^2$ (H; n = 406). Tertiles cutpoints for LB-MQ were ≤13.99 kPa/kg (L; n = 406), 14.00–17.88 kPa/kg (M; n = 407), and ≥17.89 kPa/kg (H; n = 406). Women were finally selected and included in subanalyses if they belonged to the following combinations: L-LB-MQ/L-ASMI (n = 92), H-LB-MQ/L-ASMI (n = 164), L-LB-MQ/H-ASMI (n = 163), H-LB-MQ/H-ASMI (n = 95), and M-LB-MQ/M-ASMI (medium/control group; n = 120).