Sarcopenia and Predictors of Skeletal Muscle Mass in Elderly Men With and Without Obesity

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Abstract

Objectives: The aim of this study was to determine the variables which show the highest association with muscle mass and to identify the most important predictors for muscle mass in elderly men with and without sarcopenia. **Methods:** A total of 71 men participated, aged ≥65 years. Sarcopenia was assessed using the definition of the European Working Group on Sarcopenia in Older People with determining skeletal muscle index (SMI), hand-grip strength (HGS), and Short Physical Performance Battery. In addition, maximum strength at upper and lower extremities and physical activity were measured. **Results:** Strong correlations existed between SMI and gait speed, HGS, maximum isometric strength at leg and chest press. Physical activity showed low correlations with muscle strength. Regression analysis revealed HGS and gait speed as key predictors for SMI. **Discussion:** The recommendation is measuring gait speed and HGS in clinical practice at first followed by measuring muscle mass for determining sarcopenia.

Keywords

sarcopenia, muscle mass, muscle strength, physical performance

Introduction

The term sarcopenia was first proposed by Rosenberg who used this term to describe the age-related loss of muscle mass (Rosenberg, 1989). In recent years, the European Working Group on Sarcopenia in Older People (EWGSOP) and the International Working Group on Sarcopenia (IWGS) have recommended using the presence of both low muscle mass and low muscle function for the determination of sarcopenia (Cruz-Jentoft et al., 2010; Cruz-Jentoft et al., 2014; Fielding et al., 2011). Sarcopenia is associated with different severe clinical outcomes such as physical impairment, limitation of mobility, decreased quality of life, increased risk of falls, hospitalization, and mortality (Beaudart et al., 2015; Janssen, Heymsfield, & Ross, 2002; Lauretani et al., 2003; Prado, Wells, Smith, Stephan, & Siervo, 2012). At the societal level, it leads to an increase in health care expenditures. For example, it is estimated that the United States needs to invest US$ 18 billion a year in the treatment and consequences of sarcopenia (Janssen, Shephard, Katzmarzyk, & Roubenoff, 2004).

In addition to the changes in muscle mass and function, there is also an increase in the percentage of body fat during aging, as the aging process implicates age-related changes in metabolism. This includes increase in fat mass in general and the infiltration of fat tissue in skeletal muscle (Villareal, Banks, Siener, Sinacore, & Klein, 2004). Baumgartner found in his examinations that about 15% of those with sarcopenia are also obese (Baumgartner, 2000). On its own, severe obesity may generate unfavorable health effects, for example, insulin resistance, hypertension, decreased physical performance, and reduced quality of life (Prado et al., 2012; Stenholm et al., 2008; Waters & Baumgartner, 2011).

Because of the far-reaching consequences of sarcopenia and obesity, it is important to know and to understand the relationships between the several aspects which are associated with the aging muscle, especially the decrease in muscle mass. Previous studies showed relationships between body fat and muscle strength, especially leg strength, in elderly women and men (Goodpaster et al., 2001; Visser et al., 2002). The results demonstrated that lower leg muscle mass and greater fat

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infiltration in the muscle were associated with poorer lower extremity performance. These findings are supported by a review which showed results demonstrating that obesity is more influential than low whole-body lean mass referring to mobility and functional decline (Marcus, Brixner, Ghate, & LaStayo, 2012). In addition, Sternfeld and colleagues found that higher fat mass was associated with slower gait speed and greater likelihood of functional limitation (Sternfeld, Ngo, Satariano, & Tager, 2002).

Krause, McIntosh, and Vallis (2012) assessed the relationships between fat-free mass index and anthropometric, gait, balance, and strength measures in older, sarcopenic, and nonsarcopenic persons. They found a strong correlation between fat-free mass, waist circumference, and hand-grip strength (HGS). In another study, Hairi and colleagues (2010) examined older, community-dwelling men. They evaluated the relationships between declines of muscle strength, muscle mass, muscle quality, functional limitation, and physical disability and concluded that muscle strength alone was the most useful indicator of changes in the aging muscle for use in clinical practice.

The objectives of this study were to analyze the relationships between parameters of muscle mass, muscle strength, physical performance, and physical activity in elderly men and to determine which variables have the highest impact on muscle mass. Therefore, we used the EWGSOP's definition of sarcopenia and adapted the purposes of Krause et al. to a different study population. We studied a heterogeneous sample of older community-dwelling men aged ≥65years, with and without sarcopenia and with body dimensions varying from normal to obese. To exclude the effects of gender (as reported in previous studies of sarcopenia; Kirchengast & Huber, 2009; Krause et al., 2012), we chose to study a sample of men only. We compared our results with these of similar studies, and discussed the implications of our findings for defining sarcopenia, especially for using in clinical practice.

Method

Participants

Volunteers were recruited by advertisement in the area of Cologne, Germany. Men who aged ≥65years were eligible for inclusion in the investigation. The exclusion criteria were any serious inflammatory, neurological, orthopedic, or cardiovascular diseases. Therefore, a self-reported questionnaire was used and a medical examination was conducted. In total, 71 men who met the above criteria participated. This study was approved by the Ethics Committee of the German Sport University Cologne. Each participant provided written informed consent.

Measurements

Muscle mass. The measurement of muscle mass was performed in the supine position using bioelectrical impedance analysis (BIA; EgoFit BIA series 4, monofrequency, Germany). Before the measurement, the participants had to adhere to different specifications according to Heyward (1998). This method is an inexpensive and easy-to-use method and can be carried out regardless of location. The decisive parameter for the analysis was the skeletal muscle mass, which was determined by the equation of Janssen, Heymsfield, Baumgartner, and Ross (2000). Their equation was developed not only for elderly people but also for people with sarcopenia and for using BIA (Janssen et al., 2000). The skeletal muscle mass was converted to percent, so that the so-called skeletal muscle index (SMI) resulted (Janssen et al., 2002). They used the term SMI because it adjusts for stature (body mass and size) and the mass of nonskeletal muscle tissues (Janssen et al., 2002).

Muscle strength. The measurement of the isometric HGS was performed using JAMAR hand dynamometer (Sammons Preston Rolyan, Bolingbrook, IL, USA) and was carried out alternately with the right and left hand. There were at least two attempts on each side. If there was a difference of ≥10% between the two attempts, a third attempt was performed. For the statistical analysis, the best attempt overall was taken.

After a medical examination, two different kinds of maximum strength measurement were performed on the leg and chest press machine (ERGO-FIT 4000, Pirmasens, Germany) to get more information about the strength of different muscle groups and different kinds of maximum strength. At first, the maximum isometric strength (MIS) was determined. The participants were first familiarized with the test procedure and the measuring apparatus, followed by one submaximal test attempt and three maximum attempts (Morat & Preuß, 2014). The best attempt was included in the analysis. A total isometric strength value (TIS) was additionally calculated, consisting of the sum of isometric HGS and MIS at chest and leg press. Furthermore, TIS was divided by SMI for the total relative isometric strength (TRIS).

The MIS measurement was also performed to obtain an initial value for the maximum dynamic strength measurement (MDS) at chest and leg press. The determination of MDS was performed following a standardized protocol (Baechle, Earle, & Wathen, 2008). After three warm-up attempts, up to five maximum attempts were carried out to determine the MDS. The highest weight moved was used for the statistical analysis. Relative maximum dynamic and isometric strength (RDS resp. RIS) at leg press were calculated as the maximum strength indexed by body mass because of the different body weight levels within the study population.

Physical performance. The Short Physical Performance Battery (SPPB) is an assessment tool that combines the results of gait speed, repeated chair stands (RCS), and static balance tests for higher and lower performance groups (Guralnik et al., 1994; Ostir, Volpato, Fried,

Table 1. Overview of the Methods Used and the Cutoff Points for Determining Sarcopenia.

Criterion and assessment	Cutoff points for men with BMI > 28 kg/m²	Cutoff points for men with BMI ≤ 28 kg/m²
Muscle mass		
Skeletal muscle index (%)	≤37	≤37
Muscle strength		
Hand-grip strength (kg)	≤32	≤30
Physical performance		
SPPB score	8	8
Gait speed over a 6-m course (m/s)	<1	<1

Note. BMI = body mass index; SPPB = Short Physical Performance Battery.

Chaves, & Guralnik, 2002; Simonsick et al., 2001). It has been used as a predictive tool for possible disability and mortality and can evaluate lower extremity functioning in older adults. The scores range from 0 (worst performance) to 12 (best performance). This composite of tests can also be used as single items in sarcopenia research (Cruz-Jentoft et al., 2010). For the statistical analysis in the current study, we only used gait speed and RCS because of ceiling effects in the balance section.

Physical activity. Physical activity was assessed using the German Physical Activity Questionnaire for people older than 50 years (G-PAQ50+; Huy & Schneider, 2008). Participants reported the frequency and duration for each of different types of physical activity over the last 7 days: work in household and garden, leisure time activities, exercise/sports, and occupation. Finally, the energy expenditure was calculated using body weight and the product of intensity and duration of an activity. The overall score makes a statement on how many calories (kcal) a person expended per week.

Determination of Sarcopenia

For determination of sarcopenia, the EWGSOP's definition was used with the presented cutoff points (Table 1). The cutoff points used for HGS within the EWGSOP's definition were originally calculated by Fried and colleagues (2001) who classified HGS into quartiles and adjusted the values for gender and body mass index (BMI). Related to this definition, sarcopenia is characterized by low muscle mass and low muscle strength or low physical performance. A person is characterized as nonsarcopenic if all parameters are normal, that is, above the cutoff point. In addition, the EWGSOP defined a further stage of sarcopenia, which is called presarcopenia. This stage is also characterized by low muscle mass but is accompanied with normal muscle strength and physical performance (Cruz-Jentoft et al., 2010).

Obesity

BMI is commonly used to classify overweight and obesity in adults. It is defined as a person's weight in kilograms divided by the square of his height in meters (kg/m²; World Health Organization [WHO], 2000). For adults, the WHO defines overweight with a BMI ≥ 25 kg/m² and obesity with a BMI ≥ 30 kg/m². BMI provides the most useful population-level measure of overweight and obesity as it is the same for both sexes and for all ages of adults (WHO, 2000).

Statistics

The statistical analysis was performed using the IBM SPSS statistics software (Version 22; IBM, Ehningen, Germany). The correlations were calculated using Pearson's correlation (r) to determine the relationships between muscle mass, muscle strength, physical performance, and physical activity. For these analyses, the significance level was set at α = 5%. For interpreting the strength of the relationship, Cohen's (1988) classification was used. According to this classification, a correlation coefficient of .10 is thought to represent a small association; a correlation coefficient of .30 is considered a moderate correlation; and a correlation coefficient of .50 or larger is thought to represent a large correlation.

For the regression analysis, the forced entry method was chosen to determine the parameters that can predict changes in SMI. Furthermore, this calculation was performed to determine appropriate predictor variables for SMI that could easily be used in clinical practice. Adjusted R^2, standard error values, and multicollinearity statistics were used to identify the most appropriate equation. The variables which had the highest correlation with SMI (considering the multicollinearity statistics) were added in the regression analysis.

Results

Table 2 shows the characteristics of the study population. Note that 17% of the men had a normal weight, 32% were overweight, and about half of the men (51%) were obese referring to the WHO's definition. After conducting all measurements for determining sarcopenia, 33 men could be characterized as sarcopenic, and five men as presarcopenic relating to the EWGSOP's definition; they indeed had low muscle mass, but still had good performances in HGS and gait speed. The

Table 2. Characteristics of the Study Population (N = 71) With Relevance to the EWGSOP's Definition of Sarcopenia.

Anthropometric measures			Minimum	Maximum
Age (years)	72.5 ± 3.9		65	83
Height (cm)	173.7 ± 5.3		161	186
Body mass (kg)	93.5 ± 18.7		60	152
BMI (kg/m^2)	30.9 ± 6.2		20.3	51.4
	therefore:			
	<25	n = 12 (17%)		
	25-29.9	n = 23 (32%)		
	>30	n = 36 (51%)		
Muscle mass				
SMI (%)	36.5 ± 5.9		23.5	49.3
	therefore:			
	>37	n = 33 (46%)		
	31.5-36.9	n = 22 (31%)		
	<31.5	n = 16 (23%)		
Muscle strength				
Hand-grip strength (kg)	35.1 ± 8.6		20	54
	BMI > 28 kg/m^2 (n = 45);			
	therefore:			
	>32	n = 14 (31%)		
	≤32	n = 31 (69%)		
	BMI ≤ 28 kg/m^2 (n = 26);			
	therefore:			
	>30	n = 25 (96%)		
	≤30	n = 1 (4%)		
Physical performance				
Gait speed (m/s)	1.46 ± 0.37		0.69	2.40
	therefore:			
	<1.0	n = 7 (10%)		
	1.0-1.39	n = 24 (34%)		
	≥1.4	n = 40 (56%)		
RCS (s)	12.8 ± 3.4		6.8	20.9

Note. Means ± standard deviation are shown. EWGSOP = European working group on sarcopenia in older people; BMI = body mass index; SMI = skeletal muscle index; RCS = repeated chair stands.

remaining 33 men had no sarcopenia showing good performances in all domains.

Correlations

The correlations were analyzed in the total study population and focused on SMI (Table 3). The results regarding muscle mass showed that SMI was strongly correlated with BMI ($r = -.877$), HGS ($r = .555$), RIS ($r = .563$), MIS at chest press ($r = .569$) and gait speed ($r = .724$). Physical activity assessed with G-PAQ50+ had small to moderate correlations with MDS chest press ($r = .317$) and RCS ($r = .248$). All other variables showed no significant correlations with G-PAQ50+.

Regression Analysis

Multiple linear regression was calculated with all subjects. The predictors gait speed, HGS, and RCS account for 57.1% of the variation in SMI (Table 4). By adding the b-values into the equation, the complete equation of the model is as follows:

$$y_{SMI} = 19.071 + 9.341 x_{\text{gait speed 6-m}}$$
$$+ 0.155 x_{\text{handgrip strength}} - 0.130 x_{RCS}. \tag{1}$$

For the current model, gait speed, $t(67) = 6.04$, $p < .001$, and HGS, $t(67) = 2.35$, $p = .02$, are significant predictors of SMI. The predictor RCS had no significant impact on the dependent variable, $t(67) = -1.11$, $p > .05$.

Discussion

We analyzed the relationships between parameters of muscle mass, muscle strength, physical performance, and physical activity in a heterogeneous group of elderly men. The results of the multiple correlation analysis showed strong correlations between SMI, BMI, and gait speed with $r > .6$. The regression analysis with SMI as the criterion indicated that the key predictors are gait speed and HGS in terms of muscle function. RCS was not important for the prediction of SMI. Together, these variables can explain more than 57% of the variability.

Table 3. Correlations Between All Parameters for Entire Population (N = 71).

Measures	G-PAQ50+	BMI	HGS	RDS	RIS	MIS	MDS	TIS	TRIS	GS	RCS	SMI
G-PAQ50+	I											
BMI	.156	I										
HGS	.067	−.540**	I									
RDS	.082	−.450**	.455**	I								
RIS	.070	−.538**	.691**	.706**	I							
MIS	.035	−.496**	.807**	.380**	.741	I						
MDS	.317**	−.017	.384**	.340**	.308*	.450**	I					
TIS	.112	−.331**	.793**	.506**	.873**	.914**	.502**	I				
TRIS	.194	.080	.590**	.330**	.666**	.690**	.525**	.876**	I			
GS	−.134	−.677**	.537**	.318**	.475**	.595**	.188	.453**	.131	I		
RCS	.248*	.230	−.206	−.070	−.168	−.244*	.160	−.134	.033	−.250*	I	
SMI	−.121	**−.877****	**.555****	.464**	**.563****	**.569****	.078	.412**	−.061	**.724****	−.283*	I

Note. G-PAQ50+ = German Physical Activity Questionnaire 50+; BMI = body mass index; HGS = hand-grip strength; RDS = relative dynamic strength leg press; RIS = relative isometric strength leg press; MIS = maximum isometric strength chest press; MDS = maximum dynamic strength chest press; TIS = total isometric strength; TRIS = total relative isometric strength; GS = gait speed; RCS = repeated chair stands; SMI = skeletal muscle index. All bold values indicate strong relationships ($r > .5$) with SMI.
*Correlations significant at $p \leq .05$. **Correlations significant at $p \leq .01$.

Table 4. Results of the Regression Analysis.

Model	Unstandardized coefficients		Standardized coefficients		Collinearity statistics	
	B	SE	Beta	p value	Tolerance	VIF
Constant	19.071	3.008		.000		
Gait speed: 6 m	9.341	1.547	.581	.000	.691	1.447
HGS	.155	0.066	.224	.022	.706	1.417
RCS	−.130	0.117	−.092	.271	.930	1.075

Note. Dependent variable: skeletal muscle index; $R = .756$ and $R^2 = .571$; VIF = variance inflation factor; HGS = hand-grip strength; RCS = repeated chair stands.

Correlations

The first objective of the analysis was to determine the variables with the highest association with SMI. The results revealed the strongest correlation between SMI and BMI ($r = −.877$) which can be explained by the fact that they both represent body composition. This result is considerably higher than the calculated correlation between fat-free mass and BMI ($r = .447$) in the study of Krause et al., but they used a different parameter of body composition, that is, fat-free mass index. Our study sample had a wide range of BMI and SMI because we included participants with and without sarcopenia and with obesity, overweight, and normal weight. Although the use of BMI as an index of obesity has been criticized in previous studies, it is still the primary measurement to assess obesity (Rejeski, Marsh, Chmelo, & Rejeski, 2010). Other authors suggested to use waist circumference or waist-to-hip ratio in addition to BMI (Pischon et al., 2008).

Another high correlation existed between SMI and gait speed ($r = .724$). Note that the relationship between SMI and gait speed, a parameter of physical performance, is stronger than with parameters of muscle strength. This result strengthens the importance of muscle mass and gait speed for the determination of sarcopenia. This is different to the results of Krause et al. because they showed a strong relationship between fat-free mass and HGS ($r = .633$) but not with gait speed ($r = −.023$). The reasons for this may be a longer walking distance (12m vs. 6m), different assessment tools (e.g., digital vs. pneumatic hand dynamometer), and a different population studied (assisted-living vs. community-dwelling persons). Furthermore, they investigated participants with normal weight (mean of BMI ≈ 25kg/m^2) only. In contrast, about half of our participants were obese and over 30% were overweight.

Our results strengthen the EWGSOP's definition and algorithm because they emphasized the importance of measuring gait speed by positioning it at the top of their algorithm. In their opinion, gait speed is the easiest and most reliable way to get a first impression for identifying sarcopenia in clinical practice (Cruz-Jentoft et al., 2010). Mention that measuring gait speed does not replace the determination of muscle mass, but this assessment is more extensive and needs special equipment.

Furthermore, SMI also had a strong correlation with parameters of muscle strength which are HGS, RIS, and MIS at chest press. But measuring maximum strength at chest or leg press has less ease of use than measuring HGS and is often not available in clinical practice. Previous studies showed that HGS is strongly related to lower extremity muscle function (Lauretani et al., 2003). They recommended introducing HGS in the routine of geriatric clinical practice because it is a simple, rapid, and inexpensive method.

Physical activity was assessed by the G-PAQ50+. The results of the correlation analysis showed only small to moderate relationships to MDS chest press and RCS. Similar results were shown by Garcia-Artero and colleagues (2007); they investigated the relationship between the level of physical activity and physical fitness, that is, muscle strength, and found no significant correlation between physical activity and muscle strength index.

Regression Analysis

Our second objective was to identify the most important predictors for muscle mass via multiple regression analysis. SMI was chosen as the criterion in this analysis because muscle mass is the most important factor for determining sarcopenia. In any definition used, low muscle mass is included for characterizing a person as sarcopenic (Cruz-Jentoft et al., 2014). Our analysis showed that the criterion muscle mass has accounted for most of the variance by the predictors gait speed and HGS in terms of muscle function. This confirms previous studies that could show that muscle mass and strength have an important relationship, for example, Krause et al. (2012). They showed that waist circumference and HGS had the strongest correlation with fat-free mass.

In comparison to gait speed, the influence of RCS was rather low, although this is also a functional parameter; and in both cases, the leg muscles are an important factor. In our study, the relationship was clearly stronger between SMI and gait speed than with RCS. This supports the results of Castillo and colleagues. They also did not find any relationships between fat-free mass and chair-stand test (Castillo et al., 2003). Note the large variance in our regression analysis explained by 57% because it is remarkable given the small number of added predictors.

Definition of Sarcopenia

The EWGSOP's definition of sarcopenia involves not only muscle mass and muscle strength but also physical performance. On one hand, this increases the complexity, but on the other hand, this allows the consideration of several parameters which may be important for the development of sarcopenia. The decision to use the definition of EWGSOP in the present study was in particular caused by the existing assessment tools and the presented cutoff points that are available for each of the three domains (Cruz-Jentoft et al., 2010). When using IWGS's definition of sarcopenia, an elderly person is only considered sarcopenic if she or he has slow gait speed along with low muscle mass (Fielding et al., 2011). In our study, this would have been the case in only a minority of subjects. However, low HGS was mainly the decisive criterion for being sarcopenic and not low physical performance. This problematic situation has been discussed already in several studies (Beaudart et al., 2015; Cooper et al., 2012; Cruz-Jentoft et al., 2014; Volpato et al., 2014). Our results strengthen the use of gait speed in clinical practice because this is a reliable, fast, simple, and inexpensive assessment (Cruz-Jentoft et al., 2010).

Limitations and Future Research

Our study was conducted with a small sample size that will be increased in future studies. We only included male participants, so it would be an important aspect for further studies to include women as well. It would be interesting to conduct these analyses in different populations and to compare the results, for example, community-dwelling versus assisted-living elderly persons. In our sample, we had a large heterogeneity in anthropometric variables, but overall, these men seem to have a high level of functioning. It could also be an important step to include more parameters in the analysis, for example, nutritional aspects or hormonal factors, to know more about the factors that influence the decrease of muscle mass.

Conclusion

Our findings in a heterogeneous sample of older men strengthen the EWGSOP's algorithm and definition of sarcopenia because of the strong relationships between SMI, gait speed, and HGS. In clinical practice are needed reliable, fast, and low cost measurements for determining sarcopenia. We therefore recommend measuring gait speed and HGS in clinical practice at first followed by measuring muscle mass.

Ethical Approval

Declaration of Conflicting Interests

References

Baechle, T. R., Earle, R. W., & Wathen, D. (2008). Resistance training. In T. R. Baechle & R. W. Earle (Eds.), *Essentials of strength training and conditioning* (3rd ed., pp. 381-412). Champaign, IL: Human Kinetics.

Baumgartner, R. N. (2000). Body composition in healthy aging. *Annals of the New York Academy of Sciences*, *904*, 437-448.

Beaudart, C., Reginster, J. Y., Slomian, J., Buckinx, F., Dardenne, N., Quabron, A., . . . Bruyère, O. (2015). Estimation of sarcopenia prevalence using various assessment tools. *Experimental Gerontology*, *61*, 31-37.

Castillo, E. M., Goodman-Gruen, D., Kritz-Silverstein, D., Morton, D. J., Wingard, D. L., & Barrett-Connor, E. (2003). Sarcopenia in elderly men and women. *American Journal of Preventive Medicine*, *25*, 226-231.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hoboken, NJ: Taylor & Francis.

Cooper, C., Dere, W., Evans, W., Kanis, J. A., Rizzoli, R., Sayer, A. A., . . . Reginster, J.-Y. L. (2012). Frailty and sarcopenia: Definitions and outcome parameters. *Osteoporosis International*, *23*, 1839-1848.

Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., . . . Zamboni, M. (2010). Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on sarcopenia in older people. *Age and Ageing*, *39*, 412-423.

Cruz-Jentoft, A. J., Landi, F., Schneider, S. M., Zuniga, C., Arai, H., Boirie, Y., . . . Cederholm, T. (2014). Prevalence of and interventions for sarcopenia in ageing adults: A systematic review. Report of the International Sarcopenia Initiative (EWGSOP and IWGS). *Age and Ageing*, *43*, 748-759.

Fielding, R. A., Vellas, B., Evans, W. J., Bhasin, S., Morley, J. E., Newman, A. B., . . . Zamboni, M. (2011). Sarcopenia: An undiagnosed condition in older adults. Current consensus definition: Prevalence, etiology, and consequences. International Working Group on Sarcopenia. *Journal of the American Medical Directors Association*, *12*, 249-256.

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., . . . McBurnie, M. A. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *56*(3), M146-M156.

Garcia-Artero, E., Ortega, F. B., Ruiz, J. R., Mesa, J. L., Delgado, M., Gonzalez-Gross, M., . . . Castillo, M. J. (2007). Lipid and metabolic profiles in adolescents are affected more by physical fitness than physical activity (AVENA study). *Revista Española de Cardiología*, *60*, 581-588.

Goodpaster, B. H., Carlson, C., Visser, M., Kelley, D., Scherzinger, A., Harris, T., . . . Newman, A. (2001). Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study. *Journal of Applied Physiology*, *90*, 2157-2165.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., . . . Wallace, R. B. (1994). A Short Physical Performance Battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*, *49*(2), M85-M94.

Hairi, N. N., Cumming, R. G., Naganathan, V., Handelsman, D. J., Le Couteur, D. G., Creasey, H., . . . Sambrook, P. N. (2010). Loss of muscle strength, mass (sarcopenia), and quality (specific force) and its relationship with functional limitation and physical disability: The Concord Health and Ageing in Men Project. *Journal of the American Geriatrics Society*, *58*, 2055-2062.

Heyward, V. (1998). Practical body composition assessment for children, adults, and older adults. *International Journal of Sport Nutrition*, *8*, 285-307.

Huy, C., & Schneider, S. (2008). Instrument für die Erfassung der physischen Aktivität bei Personen im mittleren und höheren Erwachsenenalter. *Zeitschrift Für Gerontologie Und Geriatrie*, *41*, 208-216.

Janssen, I., Heymsfield, S. B., Baumgartner, R. N., & Ross, R. R. (2000). Estimation of skeletal muscle mass by bioelectrical impedance analysis. *Journal of Applied Physiology*, *89*, 465-471.

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*, *50*, 889-896.

Janssen, I., Shephard, D., Katzmarzyk, P., & Roubenoff, R. (2004). The healthcare costs of sarcopenia in the United States. *Journal of the American Geriatrics Society*, *52*, 80-85.

Kirchengast, S., & Huber, J. (2009). Gender and age differences in lean soft tissue mass and sarcopenia among healthy elderly. *Anthropologischer Anzeiger*, *67*, 139-151.

Krause, K. E., McIntosh, E. I., & Vallis, L. A. (2012). Sarcopenia and predictors of the fat free mass index in community-dwelling and assisted-living older men and women. *Gait & Posture*, *35*, 180-185.

Lauretani, F., Russo, C. R., Bandinelli, S., Bartali, B., Cavazzini, C., Di Iorio, A., . . . Ferrucci, L. (2003). Age-associated changes in skeletal muscles and their effect on mobility: An operational diagnosis of sarcopenia. *Journal of Applied Physiology*, *95*, 1851-1860.

Marcus, R. L., Brixner, D. I., Ghate, S., & LaStayo, P. (2012). Fat modulates the relationship between sarcopenia and physical function in nonobese older adults. *Current Gerontology & Geriatrics Research*, *2012*, Article 216185.

Morat, T., & Preuß, P. (2014). Reliability and effects of muscular pretension on isometric strength of older adults. *European Review of Aging and Physical Activity*, *11*, 69-76.

Ostir, G. V., Volpato, S., Fried, L. P., Chaves, P., & Guralnik, J. M. (2002). Reliability and sensitivity to change assessed for a summary measure of lower body function: Results from the Women's Health and Aging Study. *Journal of Clinical Epidemiology*, *55*, 916-921.

Pischon, T., Boeing, H., Hoffmann, K., Bergmann, M., Schulze, M. B., Overvad, K., . . . Riboli, E. (2008). General and abdominal adiposity and risk of death in Europe. *The New England Journal of Medicine*, *359*, 2105-2120.

Prado, C. M. M., Wells, J. C. K., Smith, S. R., Stephan, B. C. M., & Siervo, M. (2012). Sarcopenic obesity: A critical appraisal of the current evidence. *Clinical Nutrition*, *31*, 583-601.

Rejeski, W. J., Marsh, A. P., Chmelo, E., & Rejeski, J. J. (2010). Obesity, intentional weight loss and physical disability in older adults. *Obesity Reviews*, *11*, 671-685.

Rosenberg, I. (1989). Summary comments. *The American Journal of Clinical Nutrition*, *50*, 1231-1233.

Simonsick, E. M., Newman, A. B., Nevitt, M. C., Kritchevsky, S. B., Ferrucci, L., Guralnik, J. M., & Harris, T. (2001). Measuring higher level physical function in well-functioning older adults: Expanding familiar approaches in the Health ABC Study. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *56*(10), M644-M669.

Stenholm, S., Harris, T. B., Rantanen, T., Visser, M., Kritchevsky, S. B., & Ferrucci, L. (2008). Sarcopenic obesity: Definition, cause and consequences. *Current Opinion in Clinical Nutrition and Metabolic Care*, *11*, 693-700.

Sternfeld, B., Ngo, L., Satariano, W. A., & Tager, I. B. (2002). Associations of body composition with physical performance and self-reported functional limitation in elderly men and women. *American Journal of Epidemiology*, *156*, 110-121.

Villareal, D. T., Banks, M., Siener, C., Sinacore, D. R., & Klein, S. (2004). Physical frailty and body composition in obese elderly men and women. *Obesity Research*, *12*, 913-920.

Visser, M., Kritchevsky, S. B., Goodpaster, B. H., Newman, A. B., Nevitt, M., Stamm, E., & Harris, T. B. (2002). Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: The health, aging and body composition study. *Journal of the American Geriatrics Society*, *50*, 897-904.

Volpato, S., Bianchi, L., Cherubini, A., Landi, F., Maggio, M., Savino, E., . . . Ferrucci, L. (2014). Prevalence and clinical correlates of sarcopenia in community-dwelling older people: Application of the EWGSOP definition and diagnostic algorithm. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *69*, 438-446.

Waters, D. L., & Baumgartner, R. N. (2011). Sarcopenia and obesity. *Clinical Geriatric Medicine*, *27*, 401-421.

World Health Organization. (2000). *Obesity: Preventing and managing the global epidemic: Report on a WHO consultation*. Geneva, Switzerland: Author.