Regional Muscle and Whole-Body Composition Factors Related to Mobility in Older Individuals: A Review

Jason Kidde, Robin Marcus, Lee Dibble, Sheldon Smith, Paul LaStayo

ABSTRACT

Purpose: To describe previously reported locomotor muscle and whole-body composition factors related to mobility in older individuals.
Methods: A narrative review of the literature, including a combination of search terms related to muscle and whole-body composition factors and to mobility in older individuals, was carried out. Statistical measures of association and risk were consolidated to summarize the common effects between studies.
Results: Fifty-three studies were reviewed. Muscle and whole-body factors accounted for a substantial amount of the variability in walking speed, with coefficients of determination ranging from 0.30 to 0.47. Muscle power consistently accounted for a greater percentage of the variance in mobility than did strength. Risks associated with high fat mass presented a minimum odds ratio (OR) of 0.70 and a maximum OR of 4.07, while the minimum and maximum ORs associated with low lean mass were 0.87 and 2.30 respectively. Whole-body and regional fat deposits accounted for significant amounts of the variance in mobility.
Conclusion: Muscle power accounts for a greater amount of the variance in the level of mobility in older individuals than does muscle strength. Whole-body fat accounts for a greater amount of the variance in level of mobility than does whole-body lean tissue. Fat stored within muscle also appears to increase the risk of a mobility limitation in older individuals.

Key Words: disability, fat, mobility, muscle, power, sarcopenia, strength

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RÉSUMÉ

Objectif : Décrire les facteurs préalablement observés de composition des muscles locomoteurs et de composition corporelle liés à la mobilité des personnes âgées.
Méthode : Examen narratif de la documentation, y compris une combinaison des critères de recherche liés à des facteurs de composition des muscles et de l'ensemble du corps, et à la mobilité des personnes âgées. Les mesures statistiques d'association et de risques ont été consolidées afin de résumer les effets communs aux différentes études.
Résultats : Au total, 53 études ont été examinées. Les facteurs liés aux muscles et au corps dans son ensemble comptaient pour une part importante de la variabilité de la vitesse de marche, avec des coefficients de détermination variant de 0,30 à 0,47. La puissance musculaire se retrouve constamment en une plus forte proportion que la force dans la variation de la mobilité. Les risques associés à une masse grasse élevée présentent un rapport d'incidence rapproché de 0,70, jusqu'à un maximum de 4,07, alors que les rapports minimum et maximum associés à une faible masse maigre sont de 0,87 à 2,30, respectivement. Le corps dans son ensemble et les dépôts de graisse localisés ont un rôle considérable à jouer dans la variation de la mobilité.
Conclusion : La puissance musculaire joue un rôle plus important que la force des muscles dans la variation du degré de mobilité chez les personnes âgées. La quantité totale de gras corporel a des effets plus importants sur la variation du degré de mobilité que l'ensemble des tissus maigres. Le gras dans les muscles semble aussi accroître les risques de limitation de la mobilité chez les individus plus âgés.

Mots clés : force, gras, incapacité, mobilité, muscles, puissance, sarcopénie

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INTRODUCTION

Maintaining locomotor muscle structure and function into old age is thought to preserve mobility.[1–5] Sarcopenic changes, the age-associated decrease in lean mass,[6–11] muscle strength,[12–38] and power[15,17–20,35–37,39–43] are thought to be related to mobility limitations; however, the relationships are variable,[25,28,41,42] and in some cases conflicting.[6,7,44] On the other hand, there is a sizeable body of research to support the notion that increasing fat depots, at both whole-body[10,12,33,34,38,44–58] and regional levels,[6,9,11,32,44,51] constitute an additional set of risk factors for mobility limitation.

Sarcopenia, along with increased whole-body and regional fat deposits, is a normal manifestation of old age.[4] In an effort to optimize rehabilitative countermeasures (e.g., resistance and aerobic exercise protocols), it is important to clearly understand how muscle size, strength, and power, as well as whole-body and regional composition, affect mobility in older populations. While exercise training is an effective countermeasure,[4,59–61] it is not clear which structural or functional changes should be targeted with these rehabilitation efforts. Furthermore, a collective synthesis and review of the critical cross-sectional and longitudinal studies that identify the impact of muscle and body composition on mobility has not been performed. The purpose of this narrative review, therefore, was to catalogue and synthesize the previously reported relationships between muscle and whole-body factors and mobility in older individuals.

METHODS

Search Method/Criteria

The literature search was limited to the Medline, CINAHL, PEDro, and SCIRUS databases and the private libraries of the authors. The search was restricted to cross-sectional and longitudinal research papers published in English that included subject cohorts with a mean age of 65 years and older. All search terms used stemmed from one of three categories: (1) age; (2) mobility; or (3) muscle and body composition parameters (see Figure 1). Search words and phrases were listed respective to the aforementioned categories: (1) *elderly*, *aging*; (2) *mobility*; and (3) *sarcopenia*, *body composition*, *muscle*, *fat*, *intermuscular fat*, *strength*, *power*. Search strings producing more than 300 hits were constrained by adding the word *disability* to the search string.

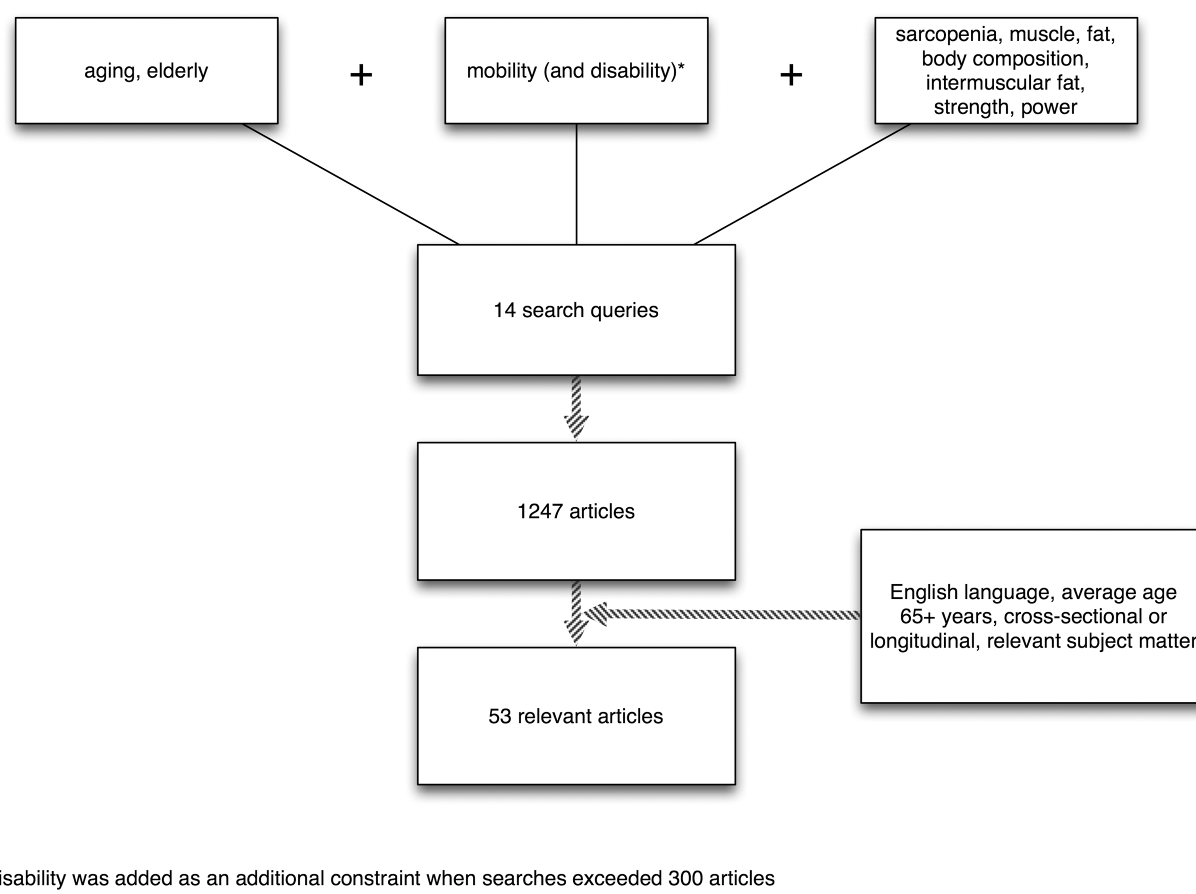

Figure 1 Search methods.

Strength/Power and Mobility Relationships

For studies assessing the relationship between strength/power and mobility and reporting correlation coefficients (Pearson's *r*), the correlation coefficient was transformed to a coefficient of determination (r^2) by squaring the reported *r*-value. This transformation was performed in order to provide consistency in summarizing the data in a tabular format. Gait speed was used as a surrogate for mobility because of the large number of studies that used gait speed as the exemplar mobility construct; gait speed has also been validated as a predictor of disability against the Estimated Population for the Epidemiologic Study of the Elderly performance battery (EPESE).[62]

Leg muscle strength was determined by the knee extensor and/or hip extensor isometric and/or isokinetic force- or torque-producing ability. Strength measures were limited to these muscle groups as a means to compare strength relationships to power relationships, given that muscle power was consistently determined by a leg-press action, which predominantly involves combined hip and knee extension. Muscle power was defined in two ways: (1) high-force, defined as efforts $\geq$70% of the maximal weight the person would be able to move through a complete range of motion (one repetition maximum, or 1RM) as quickly as possible; and (2) low-force, defined as moving a weight equivalent to 40% 1RM as quickly as possible.[39]

Whole-Body and Regional Composition and Risk of Mobility Limitation

Cumulatively, odds ratios (ORs), relative odds ratios (RORs), hazard ratios (HRs), and relative risks (RRs) were consolidated in order to simplify results. Several studies reported tiers of risk based on both the categorization of the independent variable and the number of covariates included in the model.[7,8,10,12,32,34,44,46–49,52,54,55,57] All risks reported in this analysis are based on results for the highest risk category and the model accounting for the most covariates, as a means of preventing any overlapping effect of the covariate.

Because of the varied and inconsistent descriptions of sarcopenia,[7,12,52,54,57] *reported risk* was separated into three categories based on varying operational definitions for sarcopenia. *Skeletal muscle index* (SMI) and *appendicular skeletal muscle index* (ASMI) were defined as lean mass divided by total body mass in kilograms and lean appendicular mass divided by height squared, respectively. *Sarcopenic obesity* was characterized as elevated fat mass and low lean mass, quantified independently by each study. Specifically, sarcopenic obesity was calculated either based on the highest tiers of body fat and lowest tiers of lean tissue[12,57] or via a residuals method.[52,54] Residuals were calculated as the difference of the actual value of appendicular lean mass (aLM) versus the predicted value based on a prediction model that incorporates fat mass as a predictor of a sarcopenic obese individual.[52,54] In this predictive model, a positive residual identifies a muscular individual while a negative residual identifies a sarcopenic obese individual.

High fat mass and *low lean mass* are described in both relative and absolute terms. Absolute measures include a unit of mass (i.e., kg) or cross-sectional area (i.e., cm^2) while relative measures are expressed as the value in question (fat or lean mass in kg) relative to either total body mass (kg) or height (m). Any exceptions to these definitions are addressed specifically in the text.

Determination of Cut-Points for Dichotomized and Continuous Variables

Cut-points for dichotomized or otherwise categorized continuous variables are described in the Results section below. Cut-points for composition measures were determined almost exclusively via the distribution of values across tertiles, quartiles, or quintiles, and labelling the most extreme categories of the respective variable as high or low.[9,10,12,13,32,34,44–46,48,49,52,55,57,63] Studies using the sarcopenic obesity construct via the residuals method determined cut-points using regression analysis.[52,54] The regression between calculated residuals and aLM/Ht^2 ($r = 0.88$ (men); $r = 0.71$ (women)) was dissected by lines marking the 20th percentile of the *x* (aLM/Ht^2) and *y* (residuals) axes, and all points below or to the left of these markers were considered sarcopenic or sarcopenic obese, respectively.[52,54] Other studies separated sarcopenia into two classes based on severity, defining Class I sarcopenia as muscle mass more than one standard deviation below a young healthy mean and Class II sarcopenia as muscle mass equal to more than two standard deviations below a young healthy mean.[8,12] In cases where authors differentiated between Class I and Class II sarcopenia, the latter is reported in our data, in order to maintain consistency with those studies that simply reported sarcopenia as two standard deviations or more below a young healthy mean.[7]

The parameters defining disability vary from the results of physical performance tests to those of questionnaires assessing perception of function and may include a combination of the two. Performance tests included gait speed, for which disability is defined as less than 1.2 m/s (Table 4),[34] and the EPESE physical battery, for which disability is defined as a score of less than 10 (scale = 0–12).[52] Questionnaire studies typically used variations of the Activities of Daily Living (ADL) scale and/or the Instrumental Activities of Daily Living (IADL) scale.[12,47,49,57] In these studies, answers were dichotomized into *perceived difficulty* or *no perceived difficulty* in performing itemized tasks. Values assigned to these answers (in the form of 1 = no difficulty, 0 = difficulty) were summed, and a ''disability'' score resulted when a majority of answers reported difficulty performing the listed tasks. Some studies used a two-item questionnaire in which a report of any difficulty in walking a quarter-mile or climbing 10 steps resulted in a disability classification.[9,10,13,32,44,46,48,55,63] Yet other studies combined performance tests and questionnaires, assigning performance test results a value of 1 or 0 based on the individual's ability to complete the task.[8,55]

RESULTS

Search Results

In total, 53 studies of older individuals ($\geq$65 years) were assessed. Of those studies, 34 described lower-extremity strength and power relationships with mobility;[11–28,31–43,47,50,63] 30 examined relationships between body composition and mobility;[6–10,12,13,31–34,38,44–58,63–65] and 9 had overlapping parameters.[12,13,31–34,38,50,63] Of the aforementioned studies, 3 addressed regional fat composition of the lower extremities and its relationship to mobility.[9,32,51] Subject cohorts consisted predominantly of elderly non-Hispanic white men and women (mean age = 74); the sample sizes ranged from as many as 7,120 individuals[45] to as few as 16[27] (see Table 1).

Strength/Power and Mobility Relationships

The relationships of muscle strength and muscle power, respectively, with gait speed are reported in Table 2.

Minimum and maximum r^2 values with respect to gait speed and power or strength are as follows: $r^2 = 0.18$, 0.38 when power was measured as low force; $r^2 = 0.27$, 0.93 when power was measured as high force; and $r^2 = 0.06$, 0.57 when the independent variable was strength. Of those studies that reported both strength and power relationships with mobility using a variety of mobility constructs, all but two[35,42] demonstrated that power explains more variance in mobility than strength,[15,17–20,36,37,41] and these two investigations observed a stronger ''strength'' relationship only in men. When men and women were pooled, however, the variance associated with power was double that associated with strength ($r^2 = 0.16$ vs. 0.08).[35]

Mobility measures other than gait speed (stair climb, walking distance, step mounting, sit-to-stand, tandem stand, Short Physical Performance Battery score, and self-report) demonstrated similar associations with strength ($r^2 = 0.06$ to 0.41) and power ($r^2 = 0.07$ to 0.83),[15,18,23–28,37,38,40–43] although there was some inconsistency with respect to the strength of the relationships between muscle function and stair-climbing ability.[25,28,42] General surveys of mobility limitations were also associated ($r^2 = 0.06$ to 0.18) with quadriceps strength,[14,36] though power best discriminated subjects characterized as fallers from those characterized as non-fallers.[17]

Whole-Body and Regional Composition and Risk of Mobility Limitation

The risks of a mobility limitation associated with sarcopenia and sarcopenic obesity are reported in Table 3. Risk indices across and within studies for mobility limitations demonstrated a minimum OR of 0.47 and a maximum OR of 4.58 for SMI, while ASMI yielded a minimum HR of 0.84 and a maximum HR of 4.08. Sarcopenic obesity demonstrated a minimum HR of 0.91 and a maximum OR of 2.04. Estrada et al.[11] defined relative sarcopenia and absolute sarcopenia as appendicular lean mass divided by total mass and lean mass divided by height squared, respectively. This group concluded that relative sarcopenia (mean $r^2 = 0.13$) is a better predictor of functional limitations than absolute sarcopenia (mean $r^2 = 0.06$).[11]

The risks associated with low whole-body relative or absolute lean mass and high whole-body relative or absolute fat mass (including both high and low BMIs) are reported in Table 4. Minimum and maximum values of risk indices for disability with respect to high whole-body fat mass are as follows: OR = 0.70, 4.07 for relative measures of adiposity versus OR = 1.08, 3.04 for absolute measures of adiposity. With the exception of one study,[47] the risk associated with both relative and absolute fat mass is higher for women than for men. Risks associated with low whole-body lean mass demonstrate a minimum OR of 0.97 and a maximum OR of 2.30 for relative measure of lean mass versus a minimum OR of 0.87 and a maximum OR of 1.60 for absolute measures of lean mass. Meanwhile, minimum and maximum values of risk associated with a high BMI were OR = 1.0, 5.43, while the risk values for those with low BMI were OR = 1.20, 3.44. Similar gender differences in risk profiles were observed with respect to BMI.

Only two cross-sectional studies[9,32] have examined the association of increased intramyocellular fat of the thigh on mobility. It should be noted that both of these studies measured muscle density via computed tomography, which is an indirect assessment of intramyocellular fat. One reported a small but independent risk (1.67 (95% CI: 1.16–2.41); see Table 4).[32] The other reported a small but significant ($p < 0.05$) association between intramyocellar fat and lower-extremity function in men and women ($r^2 = 0.07$ and 0.03, respectively).[9] Using dual x-ray absorptiometry (DXA) to quantify regional fat mass, another study[51] reported that leg fat mass discriminated between those with and without disability ($p = 0.01$).

Regional lower-extremity muscle mass consistently yields a small but not always independent relationship with mobility. Visser et al.[32] found that low lean muscle

Table 1 Study Demographics

Study	*Population Size*	*Age* mean ± SD / range*
Bohannon (2008)[38]	687 participants	73.6 ± 6.1 years
Jankowski et al. (2008)[58]	109 participants	60 + years
Koster et al. (2008)[46]	2,982 participants: 1,527 women, 1,455 men; 41% African Americans	74.2 ± 2.9 years
Puthoff et al. (2008)[15]	30 participants: 25 women, 5 men	77.3 ± 7.0 years
Reid et al. (2008)[6]	57 participants: 31 women, 26 men	74.2 ± 7.0 years
Stenholm et al. (2008)[34]	2,099 participants: 1,175 women, 924 men	66.6 ± 0.3 years
Bouchard et al. (2007)[56]	904 participants: 467 women, 437 men	74.1 ± 4.2 years
Bean et al. (2007)[40]	138 participants	75.4 ± 6.9 years
Buchman et al. (2007)[16]	886 participants: 664 women, 222 men	80.5 ± 6.87 years
Delmonico et al. (2007)[54]	2,976 participants: 1,548 women, 1,428 men; 41% African Americans	73.8 ± 2.9 years
Estrada et al. (2007)[11]	189 women	67.5 ± 4.8 years
Misic et al. (2007)[33]	55 participants: 36 women, 19 men	69.3 ± 5.5 years
Puthoff & Nielsen (2007)[18]	30 participants: 25 women, 5 men	77.3 ± 7.0 years
Perry et al. (2007)[17]	44 non-fallers, 34 fallers	76.2 ± 0.7 years
Schrager et al. (2007)[53]	871 participants: 493 women, 378 men	74.0 ± 7.1 years
Sergi et al. (2007)[65]	1,672 participants: 1,236 women, 1,436 men	73.2 ± 5.6 years
Lebrun et al. (2006)[50]	396 women	66.3 ± 3.8 years
Marsh et al. (2006)[19]	720 participants: 384 women, 336 men	73.0 ± 6.1 years
Sayers et al. (2005)[35]	101 participants: 64 women, 37 men	80.7 ± 0.6 years
Herman et al. (2005)[39]	37 participants: 24 women, 13 men	75.6 ± 6.6 years
Visser et al. (2005)[32]	3,075 participants: 1,345 women, 1,286 men; 34% African Americans	73.5 ± 2.9 years
Cuoco et al. (2004)[20]	47 participants: 41 women, 6 men	72.7 ± 0.8 years
Ostchega et al. (2004)[21]	1,499 participants	Age range = 50—70 years
Song et al. (2004)[64]	26 women	75.5 ± 5.1 years
Zoico et al. (2004)[12]	167 women	71.7 ± 2.4 years
Bean et al. (2003)[41]	1,032 participants: 557 women, 475 men	74.2 years
Newman et al. (2003)[52]	2,984 participants: 1,552 women, 1,432 men; 41% African Americans	73.6 ± 2.9 years
Bean et al. (2002)[37]	45 participants: 34 women, 11 men	72.7 ± 4.6 years
Davison et al. (2002)[57]	2,917 participants: 1,526 women, 1,391 men	76.8 ± 2.0 years
Ferrucci et al. (2002)[23]	620 older women	65 + years of age
Janssen et al. (2002)[8]	4,504 participants: 2,278 women, 2,224 men	70.5 ± 7 years
Ploutz-Snyder et al. (2002)[22]	100 participants	73.0 ± 0.9 years
Visser et al. (2002)[9]	3,075 participants: 1,537 women, 1,442 men; 40% African Americans	73.6 ± 2.9 years
Broadwin et al. (2001)[10]	1,051 participants: 634 women, 417 men	70.7 years (range: 55–92)
Friedman et al. (2001)[45]	7,120 participants: 3,312 women, 3808 men	71.7 ± 5.7 years
Sternfeld et al. (2002)[47]	1,655 participants: 947 women, 708 men	69.4 years (range: 55–95.5)
Foldvari et al. (2000)[36]	197 women	74.8 ± 5.0 years
Visser, Newman, et al. (2000)[63]	3,075 participants: 1,537 women, 1,442 men; 40% African Americans	73.6 ± 2.9 years
Visser, Deeg, et al. (2000)[13]	449 participants: 233 women, 216 men	75.4 ± 6.4 years
Rantanen et al. (1999)[26]	1,002 women	78.3 ± 8.1 years
Zamboni et al. (1999)[51]	144 women	72.0 ± 2.2 years
Baumgartner et al. (1998)[7]	808 participants: 382 women, 426 men	73.7 ± 6.0 years
Payette et al. (1998)[31]	30 women	81.5 ± 7 years
Visser, Langlois, et al. (1998)[55]	5,201 participants: 2,714 women, 2,095 men	72.9 ± 5.6 years
Visser, Harris, et al. (1998)[44]	753 participants: 478 women, 275 men	78.2 ± 0.4
Rantenen et al. (1996)[25]	458 participants: 315 women, 143 men	All participants were either 75 or 80 years of age
Brown et al. (1995)[27]	16 participants	80.9 years (range: 75–88)
Launer et al. (1994)[49]	426 women	66.1 ± 3.6 years
Skelton et al. (1994)[42]	100 healthy men and women	77.3 years (range: 65–89
Rantanen et al. (1994)[24]	295 participants: 191 women, 104 women	75 years
LaCroix et al. (1993)[48]	6,981 participants: 3,935 women, 3,046 men	65 + years
Bassey et al. (1992)[43]	26 participants: 13 women, 13 men	187 ± 1.6 years
Hyatt et al. (1990)[14]	92 participants: 64 women, 28 men	77 ± 6.4 years
Danneskiold-Samsee et al. (1984)[28]	52 participants: 29 women, 23 men	80 years (range: 78–81)

*Mean ± SD or a range reported when available

mass of the thigh demonstrated an increased risk (1.79 (95% CI: 1.25–2.58)) of mobility limitation, though this risk no longer existed when strength was entered as a covariate (1.40 (95% CI: 0.94–2.08)), suggesting that lean mass is mediated by strength.[32] Estrada et al.[11] also found that low lower-extremity lean mass was inversely related to mobility disability, and a more recent study suggested that for every 1 kg increase in lower-extremity

Table 2 Relationship between Power and Gait Speed and between Strength and Gait Speed in Older Individuals (>65 years of age)

	Mean Gait Speed	*Gait Speed Protocol*	*High-Force, Low-Velocity Power and Gait Speed r^2*	*Low-Force, High-Velocity Power and Gait Speed r^2*	*Strength and Gait Speed r^2 (Strength-testing Method)*
Puthoff et al. (2008)[15]	0.72 m/s	Intensity: Habitual Course: 4 m	0.50	0.38	0.39 (Isotonic leg press)
Puthoff & Nielsen (2007)[18]	0.97 m/s	Intensity: Habitual Course: 4 m	0.35	0.31	0.31 (Isotonic leg press)
Bean et al. (2007)[40]	0.93 m/s	Intensity: Not indicated Course: 4 m	0.34 (70% 1RM)	0.34	n/a
Marsh et al. (2006)[19]	1.2 m/s	Intensity: ''steady pace'' Course: 400 m	0.58	n/a	0.53 (Isometric sum score of hip, knee and ankle)*
Misic et al. (2007)[33]	No mean reported	Intensity: Habitual Course: 7 m	n/a	n/a	0.21 (sum of isokinetic knee extension and flexion)
Herman et al. (2005)[39]	1.21 m/s	Intensity: Habitual Course: 4 m	0.27	0.26	n/a
Sayers et al. (2005)[35]	0.87 m/s	Intensity: ''self-paced'' Course: 400 ms	n/a	0.18	0.06 (Isotonic leg press)
Cuoco et al. (2004)[20]	1.12 m/s	Intensity: Habitual Course: 2+ m	0.26 (70% 1RM)	0.35	0.07 (Isotonic leg press)
Ostchega et al. (2004)[21]	0.95 m/s	Intensity: Habitual Course: 20 feet	n/a	n/a	0.20 (Isokinetic knee extension)
Bean et al. (2003)[41]	1.08 m/s	Intensity: Habitual Course: 4 m	0.41	n/a	0.38 (Isometric Hip extension) 0.36 (Isometric knee extension)
Bean et al. (2002)[37]	1.18 m/s (habitual) Note: Maximal mean gait speed not reported	Intensity: Habitual and maximal Course: 2+ meters	Habitual: 0.61 Maximal: 0.56	n/a	Habitual: 0.57 (Isotonic leg press) Maximal: 0.56 (Isotonic leg press)
Ploutz-Snyder et al. (2002)[22]	70% had no difficulty walking 1.22 m/s	Intensity: Maximal Course: 25 feet	n/a	n/a	0.27 (Isometric knee extension)
Brown et al. (1995)[27]	Min.–Max. =0.5–1.5 m/s	Intensity: Habitual Course: Not reported	n/a	n/a	0.20 (Isometric knee extension)
Bassey et al (1992)[43]	Male: 2.2 m/s Female: 1.37 m/s Combined: 1.79	Intensity: Habitual Course: 6.1 m	Female: 0.93 Male: 0.58 Combined: 0.80	n/a	n/a

*Muscles tested: hip—abductors, adductors, flexors, extensors; knee—flexors, extensors; ankle—dorsiflexors, plantarflexors
''self paced'' = 400 m walk effort in which gate speed is neither maximal or habitual but, rather, paced at the speed the individual felt he or she could maintain for the entire 400 m

lean mass there was a 53% reduction in mobility limitation.[6] Furthermore, the same study demonstrated a notably larger lean mass in individuals scoring >7 on the Short Physical Performance Battery (SPPB) (scale = 0–12) than in those scoring below this threshold of mobility.[6]

DISCUSSION

It seems intuitive that muscle is intricately linked to an older individual's level of mobility; however, there is debate as to which specific muscle parameters are most influential. A review of the literature on muscle strength, power, and composition reveals strong trends suggesting that muscle power has a stronger association with mobility than does muscle strength,[15,17–20,36,37,39,41] and that high whole-body fat mass is more influential than low whole-body lean mass with respect to mobility.[12,32,44,46,47,50–52,54,55,57,58,63]

The association between strength and mobility is discrete, in that if an individual is not capable of producing the force required to functionally ambulate, rise from a chair, or negotiate stairs, the consequences are obvious. However, most, if not all, daily activities are performed at sub-maximal intensities, and in most cases there is a spectrum of ability; the outcomes cannot simply be reduced to ''able'' or ''not able.'' Along the continuum of the mobility–strength relationship, the association becomes less discrete as confounding influences enter into this relationship, as represented by the moderate coefficients of determination presented in Table 2. Power correlates better than strength with all mobility measures,[15] which has piqued some investigators' interest in assessing power by emphasizing its constituent parts.[15,18,20,39,40] Distinguishing the power generated by a muscle at a high percentage (90–100%) of 1RM from that generated by a muscle at a low percentage (40%) of 1RM emphasizes the force component and the velocity component of power, respectively. Since power represents force per unit time, some have proposed that power produced under the low-load, high-velocity condition would best predict mobility, since time is the differentiating factor between strength and power.[20,40] Contrary to this hypothesis, it has been shown that power measured under the high-load, low-velocity condition best correlates with gait speed and other mobility

Table 3 Reported ''Risk'' (Odds and Hazard) Ratios for Mobility-Related Functional Limitations and Disabilities in Relation to Various Indices of Sarcopenia

	Sarcopenia Cut-offs / Definitions	*SMI**	*ASMI**	*SO**	*Covariates*	*Functional Limitations and Disability Criteria*
Delmonico et al. (2007)[54]	ASMI: M: < 7.25 kg/ht^2 F: < 5.67 kg/ht^2 SO: 20th percentile of residuals distribution in relation to ASMI		HR: M: 0.84 (0.66–1.08) F: 1.04 (0.82–1.31)	HR: M: 0.91 (0.73–1.15) F: 1.34 (1.11–1.61)	ASMI: Age, race, comorbidity, lower-extremity function, and interim hospitalization (SO additionally adjusted for physical activity and body mass)	Self-report: Difficulty walking ¼ mile or climbing 10 steps
Zoico et al. (2004)[12]	ASMI: < 4.7 kg/ht2 SMI: < 23.1% SO: < 5.3kg/m^2 lean and > 45.6% fat	OR: M/F: 3.86 (1.01–14.87)	OR: M/F: 0.98 (0.35–2.78)	OR: M/F: 2.16 (0.73–6.42)	Age, heart disease, hypertension, diabetes and arthritis, BMI, ASMI, and SMI	Self-report: Difficulty performing majority of ADLs/IADLs
Newman et al. (2003)[52]	ASMI and SO: Lower 20th percentile respective to distribution of each method		OR: M: 1.5 (1.1–2.1) F: 0.9 (0.7–1.2)	OR: M: 1.8 (1.3–2.5) F: 1.9 (1.4–2.5)	Age, race, drinking, smoking, physical activity, and comorbidity	Performance: EPESE physical battery score < 10
Davison et al. (2002)[57]	SO: Lowest 2 quintiles lean and highest 2 quintiles fat			OR: M: 1.49 (0.87–2.36) F: 2.04 (0.92–4.53)	Age, ethnicity, education, hypertension, heart disease, stroke, hip fracture, and arthritis (Type II diabetes mellitus for women)	Self-report: Difficulty on majority of walking ¼ mile, climbing 10 steps, carrying 10 pounds, crouching, and rising from chair
Janssen et al. (2002)[8]	SMI: M: < 31.5% F: < 22.1%	OR: M: 0.47–4.58** F: 0.30–3.96**			Age, race, BMI, health behaviours, and comorbidity	Performance: Inability to complete 8 ft walk, 5 chair stands, or tandem stand Self-report: Reported difficulty on majority of walking ¼ mile, climbing 10 steps, carrying 10 pounds, crouching, and rising from chair
Baumgartner et al. (1998)[7]	ASMI: M: < 7.26 kg/ht^2 F: < 5.45 kg/ht^2		OR: M: 3.66 (1.42–10.02) F: 4.08 (1.52–11.31)		Age, ethnicity, obesity, income, alcohol intake, physical activity, current smoking, and comorbidity	Self-report: New Mexico Elderly Health Survey—report of ≥ 3 disabilities

SMI = skeletal muscle index (total lean mass (kg)/total mass (kg) × 100); ASMI = appendicular skeletal muscle index (total lean appendicular mass (kg)/Height^2); SO = sarcopenic obesity (inclusion of high fat + low lean mass, which is individually described by each study); ADL = activities of daily living; IADL = instrumental activities of daily living; EPESE = Estimated Population for the Epidemiologic Study of the Elderly; OR = odds ratio; HR = hazard ratio; BMI = body mass index; M = male; F = female

*Indices of ''Risk'' are reported as OR or HR (95% CI).

**No single definition of disability was reported. Therefore a range is presented based on the individual ORs associated with various self report and functional measures.

Table 4 Reported "Risk" (Odds Ratio and Relative Odds Ratio) for Mobility-Related Functional Limitations and Disabilities in Relation to Whole-Body and Regional Composition of Fat and Lean Tissue

	Cut-Offs	*Whole-Body Composition**	*BMI**	*Regional Composition**	*Covariates*	*Functional Limitations and Disability Criteria*
Koster et al. (2008)[46]	Cut-off: High Fat M: > 31.3% F: > 43.7% Cut-off: High BMI ≥ 30	HR: High Fat M: 1.31 (0.93–1.84) F: 2.03 (1.51–2.72)	HR: High BMI M: 1.64 (1.18–2.27) F: 2.19 (1.65–2.89)		Age, site, marital status, education, smoking (pack-years), SPPB score, self-rated health, heart disease, cerebrovascular disease, Peripheral Arterial Disease, diabetes mellitus, lung disease, osteoarthritis, cancer, depression, cognitive impairment	Self-report: Difficulty walking ¼ mile or climbing 10 steps
Stenholm et al. (2008)[34]	Cut-off: High Fat M: > 29.2% F: > 40.1% Cut-off: High BMI ≥ 35	OR: High Fat M and F combined: 2.53 (1.70–3.77)	OR: High BMI M and F combined: 5.43 (3.46–8.50)		BMI: Age, sex High Fat: Age, sex, education, smoking, alcohol consumption, hypertension, cardiovascular disease, pulmonary disease, joint disease, diabetes mellitus, anti-inflamatory drug use, estrogen, C-reactive protein, hand-grip strength, height	Gait speed: < 1.2m/s = limitation
Visser et al. (2005)[32]	Cut-off: High Fat None reported Cut-off: Intramyocellular Fat M: < 34 HU F: < 30 HU Cut-off: Lean CSA M: < 235 cm^2 F: < 166 cm^2	OR: High Fat M: 1.18 (0.77–1.80) F: 2.73 (1.91–3.91) *Note:* Fat reported in absolute fat mass (kg)		OR: Intramyocellular Fat M: 1.79 (1.22–2.65) F: 1.55 (1.10–2.17) OR: Lean CSA M: 1.45 (0.92–2.27) F: 1.34 (0.95–1.88)	Age, race, study site, height, total-body fat mass, education, alcohol consumption, smoking status, physical activity, prevalent disease, self-rated health, depression, cognitive status, strength, muscle CSA, muscle attenuation	Self-report: Difficulty walking ¼ mile or climbing 10 steps
Zoico et al. (2004)[12]	Cut-off: High Fat F: > 45.6% Cut-off: Low Lean F: < 5.3kg/m^2 Cut-off: High BMI F: > 30	OR: High Fat F: 3.07 (1.02–9.25) OR: Low Lean F: 2.30 (0.79–6.66)	OR: High BMI F: 4.56 (1.51–13.77)		Age, heart disease, hypertension, diabetes, arthritis	Self-report: Difficulty performing majority of ADLs/IADLs
Davison et al. (2002)[57]	Cut-off: High Fat (absolute) None reported (relative) M: 40.15–57.15% F: 43.48–67.07% Cut-off: Low Lean (absolute) None reported (relative) M: 5.88–8.46 kg/m^2 F: 3.73–5.96 kg/m^2 Cut-off: High BMI M/F: ≥ 35 Cut-off: Low BMI M/F: < 18.5	OR: High Fat (absolute) M: 1.24 (0.76–2.01) F: 2.60 (1.89–3.59) OR: High Fat (relative) M: 1.87 (1.19–2.96) F: 2.74 (1.43–5.25) OR: Low Lean (absolute) M: 1.25 (0.71–2.20) F: 1.09 (0.62–1.93) OR: Low Lean (relative) M: 1.20 (0.61–2.35) F: 0.87 (0.43–1.77)	OR: High BMI M: 2.26 (1.04–4.94) F: 4.81 (2.33–9.91) OR: Low BMI M: 1.85 (0.70–4.89) F: 3.44 (1.31–9.06)		M: Age, ethnicity, education, diabetes mellitus, hypertension, heart disease, stroke, hip fracture, arthritis F: Age, ethnicity, education, heart disease, stroke, hip fracture, arthritis	Self-report: Difficulty on the majority of walking ¼ mile, climbing 10 steps, carrying 10 pounds, crouching, and rising from chair
Sternfeld et al. (2002)[47]	Cut-off: High Fat M/F: > 90^{th} percentile fat mass (kg)	OR: High Fat M: 1.09 (1.05–1.12) F: 1.08 (1.06–1.10)			Age, comorbidity, self-reported physical activity, smoking status	Self-report: "A lot of difficulty" performing or "unable to perform"

	Cut-off: Low Lean M/F: < 10th percentile lean mass (kg)	OR: Low Lean M: 0.97 (0.90–1.04) F: 1.00 (0.93–1.07)				stooping/crouching/ kneeling, carrying more than 10 pounds, walking up and down stairs
Broadwin et al. (2001)[10]	Cut-off: High Fat M: 23.8–46.0% F: 33.1–55.0% Cut-off: Low Lean M: 35.5–75.6% F: 45.6–67.0%	OR: High Fat M: 0.7 (0.1–9.9) F: 1.9 (0.7–5.2) OR: Low Lean M: 1.1 (0.1–10.0) F: 1.6 (0.6–4.2)			Age, chronic diseases, alcohol use, education, depression, smoking, current estrogen use	Self-report: Difficulty walking ¼ mile or climbing 10 steps
Friedman et al. (2001)[45]	Cut-off: High BMI M/F: ≥ 40		ROR: High BMI M: 4.21 (1.76–10.03) F: 4.68 (2.68–8.16)		Age, polypharmacy, depression	Self-report: Difficulty performing majority of ADLs/IADLs
Visser, Harris, et al. (1998)[44]	Cut-off: High Fat M: > 32.0% F: > 43.7% Cut-off: Low Lean (total) M: < 51.2 kg F: < 35.2 kg (lower extremity) M: < 16.8 kg F: < 11.3 kg	OR: High Fat M: 3.04 (1.09–8.50) F: 4.07 (2.00–8.28) OR: Low Lean (total) M: 1.61 (0.50–2.43) F: 0.39 (0.18–0.85)		OR: Low lean (lower extremity) M: 2.01 (0.62–6.53) F: 0.53 (0.25–1.14)	Age, education self-rated health, chronic illness, physical activity, smoking, alcohol use, estrogen use (women only), height	Self-report: ''A lot of difficulty'' performing or ''unable to perform'' stooping/crouching/ kneeling, standing for 15 minutes, or ½ mile walk
Visser, Langlois, et al. (1998)[55]	Cut-off: High Fat M: > 37.5 kg F: > 42.4 kg Cut-off: Low Lean M: < 43.5 kg F: < 29 kg	OR: High Fat M: 2.77(1.82–4.23) F: 3.04 (2.18–4.25) OR: Low Lean M: 0.79 (0.53–1.18) F: 0.79 (0.57–1.08)			Age, education, depression, chronic illness, edema, physical activity, recent weight loss, smoking, alcohol use, study site, chronic illness during follow-up	Self-report: Difficulty walking ¼ mile or climbing 10 steps
Launer et al. (1994)[49]	Cut-off: High BMI F: > 28.1		OR: High BMI F: 1.78 (1.06–3.01)		Aging, smoking status, socio-economic status as measured by years of education, study time	Self-report: Difficulty walking 400m; walking across a room; climbing 2 steps; doing heavy chores; running errands; bending to the floor; or transferring from a car, bed, bath, or toilet
LaCroix et al. (1993)[48]	Cut-off: High BMI M/F: > 80th percentile Cut-off: Low BMI M/F: < 20th percentile		RR: High BMI M: 1.0 (0.9–1.2) F: 1.0 (0.9–1.1) RR: Low BMI M: 1.2 (1.0–1.5) F: 1.4 (1.2–1.6)		Community, age, behavioural risk factors, chronic disease	Self-report: Difficulty walking ¼ mile or climbing 10 steps or descending 10 steps

HU = Houndsfield units; HR = hazard ratio; OR = odds ratio; ROR = relative odds ratio; RR = relative risk; BMI = body mass index; SPPB = Short Physical Performance Battery; CSA = cross-sectional area; M = Male; F = Female
*Indices of ''Risk'' are reported as OR, HR, RR, or ROR (95% CI).

measures,[15,18] while others have found little or no difference between the measures.[39,40] Although the speed of contraction cannot be discounted, it does appear that the force component of power is the predominant piece of the power–mobility relationship, which may have therapeutic implications. Indeed, traditional resistance training, which focuses on force enhancement, has been shown to improve power in the elderly population to a similar extent as power-specific exercises.[59]

Normalizing strength to muscle cross-sectional area, frequently referred to as ''muscle quality,'' improves the strength–mobility relationship to a similar extent as power alone.[33] Specifically, Misic et al.[33] described an improvement from an r^2 of 0.29 ($p < 0.05$) for strength and mobility to 0.42 ($p < 0.05$) for muscle quality and mobility.[33] Unfortunately, no studies to date have assessed power normalized to muscle size in relation to mobility in the elderly, so it is not known whether the power relationship would further improve if expressed as power per unit of muscle size. Some evidence exists, however, that suggests the plausibility of this relationship.[66] Future studies should assess power produced per unit of muscle size as it pertains to mobility, since this could either underscore power-specific muscle factors or demonstrate that power and muscle quality are equally good predictors of mobility.

Studies of whole-body composition have emphasized the impact of fat mass rather than lean mass on disability. Every study included in this review found that increased fat mass was a significant predictor of either current mobility limitation[9,12,32,44,46,47,50–52,54,55,57,58,63] or future disability,[10,49,54] while few demonstrated an influence of lean mass on mobility (see Tables 3 and 4).[6–11] Bouchard et al.[56] measured fat mass and lean mass in relation to physical capacity and found that only fat mass had an influence.[56] This group cautioned against using BMI as a body-composition assessment, noting that it is increasingly invalid in older populations as an assessment of composition. Despite these cautionary remarks, Jankowski et al.[58] demonstrated that BMI was nearly as good of a predictor of mobility limitation as a fat index (fat mass/total body mass) via poor performances on the Continuous Scale Physical Function Performance test (CS-PFP) ($r^2 = 0.50$ vs. $R^2 = 0.54$) and the Short Form-36 (SF-36) ($r^2 = 0.34$ vs. $r^2 = 0.37$). Several other studies have supported the notion that BMI is a valid surrogate for body fatness in the elderly with respect to disability risk and that this assessment is cost effective and feasible.[12,34,38,45,46,48,57,65] Other studies investigating the relationship between body composition and mobility are difficult to present in total, since various other fat and mobility measures were employed.[31,50,51] In general, these disparate studies suggest that increasing fat mass (both total body and regional) may affect functional mobility as much as or more than lean mass.[31,50,51] For example, no relationship has been reported between lean mass and a timed up-and-go test.[31] Further, an additional 10 kg of fat mass can result in a reduction in physical activity and physical performance[50] and can serve to discriminate between those with and those without disability.[51]

Contrary to the above observations, some studies have demonstrated that lean tissue affects mobility in the elderly population.[6–11] Some of these studies use indices such as the percentage of lean mass; therefore, the effect of fat cannot be discounted.[8,10] Visser et al. determined that low lean mass was not predictive of disability[13,44,55,63] but years later described muscle mass as being predictive of disability.[9] Most recently, Visser et al.[32] concluded that muscle mass predicts disability but that the relationship is mediated by strength.[32] On the other hand, Baumgartner et al.[7] found an approximately fourfold increased risk for mobility limitation in those with the lowest lean mass, as assessed by appendicular lean mass/height;[2,7] however, these authors did not measure strength, and, therefore, the possibility of this mediating relationship cannot be discarded.[7] Of course, the possibility that strength mediates the relationship between lean mass and mobility does not negate the importance of lean mass as a predictor of mobility. It does, however, highlight the fact that other intrinsic muscle factors, irrespective of muscle size, are important strength-training outcomes and that strength and power may be more clinically important endpoints than hypertrophy.

There is an increasing body of literature suggesting that regional fat mass affects both muscle quality[67–69] and measures of mobility and physical performance in older individuals.[9,32,51] The role of leg fat, as measured via DXA, is associated with an increased risk of mobility limitation,[51] though the role of low lean mass in the legs is questionable.[6,51] Although Reid et al.[6] recently demonstrated a decreasing OR (0.47 (95% CI: 0.22, 0.89)) for disability with every 1 kg increase in leg-muscle mass, this group admittedly acknowledged a limitation in that they did not investigate the role of regional fat mass and, in particular, fat infiltration of skeletal muscle.[6] Only one study to date has identified intramyocellular fat as increasing the risk of mobility limitation independent of strength or whole-body fat mass,[32] although recently others have suggested that fat inside and outside the muscle cells of calf muscles can adversely affect physical performance in older, obese individuals.[69] More research is warranted to determine whether or not this relationship persists. Recently, we have identified intramuscular fat (a total of intra- and extramyocellular fat independent of subcutaneous fat) of the thigh musculature as being inversely associated with the number of steps taken per day and the distance walked in 6 minutes, though knee-extension force was most related to the timed up-and-go manoeuvre and to negotiating stairs.[70]

Limitations exist in narrative reviews of the literature that can restrict their usefulness. A major limitation in reviewing only cohort cross-sectional studies is that causal relationships cannot be determined. Evaluation of the findings for the control arm of even a few longitudinal cohort (and ideally randomized) studies would permit better understanding of the temporal relationship between body composition and mobility. In this review we have attempted to minimize these limitations by providing a transparent outline of the search strategy and terms, constraining the studies to those whose aim was to determine association and risk, and providing adequate detail on each study so that readers can decide for themselves the impact of muscle-function and composition factors on mobility in older individuals. Despite an effort to constrain the criteria for inclusion for each paper, the literature cited within this review varies extensively in terms of cohort demographics, outcome measures, measurement tools, statistical methods, and definitions of terms. With more than 50 included studies, however, we feel that our narrative review strongly represents the relationships between and the associated risks of sarcopenic and age-related changes in body composition. Furthermore, we feel that limiting the manuscript to cross-sectional and longitudinal studies was necessary to mitigate the potential confounding influence of rehabilitation countermeasures. We have added substantial detail from the included studies, but warn the reader that efforts to determine and integrate complex interactions within and across studies can never be conclusive. Although different methodological approaches across studies may partially explain the variability in outcomes, we found relative consistency among the outcomes, which lends credence to the generalizability of our narrative conclusions.

CONCLUSION

Muscle composition and function are subject to change during the latter third of life. Of particular concern are age-related declines in strength and power, which are likely affected by increasing total fat mass as well as by fat stored within whole muscle and the muscle cell. Fat mass also appears to have some independent effect on mobility, aside from its role in decreasing strength and power. Loss of lean muscle tissue is also related to mobility, but not to the same extent as muscle function and whole-body fat composition. Lastly, other intrinsic factors of muscle appear to be of more concern than lean mass with respect to mobility, which suggests that in this population, gains in muscle force and power production may be more influential than muscle hypertrophy as it relates to mobility.

CLINICALLY RELEVANT SUMMARY

Age-related changes in muscle function and regional and whole-body composition are modifiable in older populations.[4,59–61,71,72] Countermeasures aimed at enhancing muscle power will likely have a positive impact on mobility.[35] While it seems intuitive that simply increasing muscle mass is important, increases in lean tissue and decreases in regional and whole-body fat deposits with rehabilitation countermeasures are often coupled to the muscle-growth response.[71] Recent evidence also suggests that resistance exercise may be a mode of exercise that can positively affect muscle and whole-body composition changes in older individuals.[71] This review highlights the clinically important role of muscle and whole-body composition in mobility among older individuals and suggests that, moving forward, clinicians should include in their tests of effectiveness a description of changes in muscle function as well as clinically feasible measures of regional and whole-body composition.

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