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Muscle mass and muscle function over the adult life span: A cross-sectional study in Flemish adults

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A R T I C L E I N F O

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A B S T R A C T

Background: Aging is accompanied with a progressive deterioration of skeletal muscle mass (SMM) and muscle function, also termed sarcopenia.
Methods: The aim was to describe SMM (based on bioelectrical impedance) and muscle function of the leg extensors over the adult age span in 819 men and 578 women, aged 18–78 years. The distribution of skeletal muscle index (SMI; SMM/height^2) groups was described and muscle force–velocity characteristics were examined between SMI-groups over the adult life span. Subjects were divided into age categories and SMI groups to compare their muscle strength characteristics. Isometric and isokinetic strength, ballistic movement speed and muscular endurance of the knee extensors were evaluated on a Biodex dynamometer.
Results: Age by gender interaction effects were found significant ($P < 0.01$) for all strength tests. In general, the overall drop in slow and faster knee extension strength was larger than the isometric component, with women showing larger losses by the age of 60–70 years compared to men. Regression analysis revealed significant ($P < 0.01$) age-related reductions, with the largest explained variance for the muscular endurance parameter (24%). No age by SMI-group interaction effect was observed for muscle function, but main effects of age and SMI were significant ($P < 0.01$).
Conclusion: The age-related decline in muscle function was stronger in women. Furthermore, a low SMI results in a weaker muscle function compared to a normal SMI in each age-category, pointing out that its relationship with physical disability should therefore be further examined over the adult life-span.

1. Introduction

A normal part of ageing is the progressive deterioration of skeletal muscle mass accompanied by significant decreases in muscle function (strength or performance), a condition also known as sarcopenia (Cruz-Jentoft, Baeyens, Bauer, Boirie, Cederholm, & Landi, 2010). This change in muscle characteristics has significant consequences for the elderly, such as a reduced mobility, a higher risk of fall related injury and impaired quality of life (Campbell, Borrie, & Spears, 1989; Reid, Naumova, Carabello, Phillips, & Fielding, 2008; Rizzoli et al., 2013). Since the Belgian elderly population (≥65 years) is estimated to reach a total of 3,326,205 in 2060 (26.27% of the total population), understanding how muscle characteristics change over adult life span will become a major public health concern (Federaal Planbureau, 2008).

During early life, muscle mass is known to progressively increase until it reaches its peak around the age of 24 years (Deschenes, 2004; Lexell, 1995; Sayer et al., 2008). Afterwards it is maintained quite well throughout the fifth decade with a moderate decline of about 10% (Lexell, 1995; Deschenes, 2004). However, this decline in muscle mass accelerates over the age of fifty leading to an annual decrease up to 1.4% (Deschenes, 2004; Lang et al., 2010; Mitchell et al., 2012; von Haehling, Morley, & Anker, 2010). In total, a reduction of approximately 40% in muscle mass and a decline in cross-sectional area of ~20% can be seen by the age of eighty (Deschenes, 2004; Evans, 2010). These changes in muscle mass have been confirmed by numerous studies (Frontera et al., 2000; Hughes et al., 2001; Janssen, Heymsfield, Wang, & Ross, 2000b).

At present, several methods are available to evaluate muscle mass, however most of them are sophisticated imaging techniques such as computerized tomography (CT) and magnetic resonance imaging (MRI). An inexpensive, non-invasive and reliable alternative is bio-electrical impedance analysis (BIA). This technique is sufficiently accurate to determine human body

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composition, and it is in this regard that Janssen, Heymsfield, Baumgartner, and Ross (2000a) developed and validated a regression equation to predict skeletal muscle mass (SMM). Using this equation they attempted to determine skeletal muscle cutpoints for identifying elevated physical disability risk in older adults (Janssen, Baumgartner, Ross, Rosenberg, & Roubenoff, 2004).

In 4499 elderly subjects ($\geq$60 years), physical disability was assessed using a questionnaire and skeletal muscle mass was determined by BIA. Absolute muscle mass (kg) was then normalized for height (m) and defined as the skeletal muscle index (SMI, kg/m^2). In women, the SMI cutpoints were 5.76–6.75 and $\leq$5.75 kg/m^2 for moderate and high physical disability risk, respectively. Higher cutpoints were found in men, with values of 8.51–10.75 and $\leq$8.50 kg/m^2 (Janssen et al., 2004). The likelihood of physical disability was increased if SMI values were lower than these cutpoints. Similar studies have been performed previously to associate sarcopenia with physical disability, although they did not consider the relation between skeletal muscle mass and physical disability (Baumgartner et al., 1998; Janssen, Heymsfield, & Ross, 2002; Melton et al., 2000).

It is well known that advancing age also has an impact on muscle function. This is the action generating capacity of the muscle mass, therefore referring to muscle strength and muscle power. However, despite the fact that it is generally accepted that the age-related loss of muscle mass is the primary cause of this loss in muscle function, there appears to be a discrepancy between the two. The age-related change in muscle function is more pronounced than the change in muscle mass. For muscle strength, a loss becomes apparent after the age of fifty years. From thereon annual decreases of about 1.5% per year are reported between the ages of 50 and 60 years. After the sixth decade, declines even increase amounting up to 3% per year (Baumgartner et al., 1998). The largest decrease, however, is observed for the age-related change in muscle power (work done per unit time). Its onset can be observed at the age of 40 years and power is thereafter reduced with 3–4% per year (Melton et al., 2000).

The aim of the current study was to describe muscle mass and muscle force–velocity characteristics of the leg extensors during the adult life span and compare them between males and females. It was our hypothesis that a decrease in muscle mass and muscle function would become more apparent with advancing age, and earlier and larger in women compared to men. Since SMI has been linked with physical disability, a description of the distribution in Skeletal Muscle Index-groups was made across the entire adult life span in Flemish adults. Furthermore, muscle force–velocity characteristics were examined between SMI-groups over the adult life span, where it was expected that a low or poor SMI would result in lower muscle function and that lower SMI groups would show a faster decrease compared to the normal SMI group with ageing.

2. Methods

2.1. Subjects

Data for this study were gathered in the framework of the first generation Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH) between October 2002 and April 2004. The purpose of this cross-sectional survey was to examine the relationship between physical activity, physical fitness and several health parameters in a randomly selected community sample of 18- to 80-year-old subjects in Flanders, Belgium (Wijndaele et al., 2007). Subjects were asked to visit the SPAH examination center to go through a medical examination, anthropometric measurements, physical tests, and a number of physical activity and health-related questionnaires. Subjects were excluded in the event of a cardiovascular disease (aortic valve stenosis, mitral insufficiency, abnormal heart auscultation or electrocardiogram; systolic blood pressure >160 mm Hg and/or diastolic blood pressure >100 mm Hg; sudden death of father or brother before the age of 45, or of mother or sister before the age of 55), acute thrombosis, recent surgery, neurodegenerative or neuromuscular disease, infection or fever, diabetes or pregnancy. In the current study, results are based on data of 819 men and 578 women, aged 18–78, of Flemish Caucasian origin. Prior to participation, study purpose and procedures were explained and subjects gave their written informed consent. Ethical approval for this study was provided by the Medical Ethics Committee of the KU Leuven. Research was conducted in consensus with the Helsinki Declaration.

2.2. Outcome measurements

The measurements performed in the current longitudinal study have been previously described elsewhere (Wijndaele et al., 2007). A concise overview is presented here below and supplemented where necessary.

2.2.1. Anthropometry

Anthropometric measurements were completed by trained staff using standardized techniques and equipment. All subjects were barefoot and wore minimal clothing. Height was measured to the nearest millimeter using a Holtain stadiometer (Holtain, Crymych, UK) and weight was measured to the nearest 0.1 kg using a digital scale (Seca 841, Seca GmbH, Hamburg, Germany). Body Mass Index (BMI) was calculated as [weight (kg)/(height (m))^2].

2.2.2. Body composition

Percentage body fat (%BF) was obtained by performing a bio-electrical impedance analysis (BIA) according to standardized procedures. Fat mass (FM, kg) and fat free mass (FFM, kg) were calculated for each subject based on the %BF.

2.2.3. Skeletal muscle mass

The following BIA equation of Janssen et al. (2000a) was used to calculate whole-body skeletal muscle mass (SMM):

$$\text{SMM (kg)} = \left[\left(\frac{\text{height}^2}{\text{BIA} - \text{resistance} \times 0.401}\right) + (\text{gender} \times 3.825) + (\text{age} \times -0.071)\right] + 5.102$$

where height is in cm; BIA-resistance is in ohms; for gender, men = 1 and women = 0; and age is in years. Janssen et al. (2000a) developed and cross-validated this equation against magnetic resonance imaging measures of whole-body-muscle mass in a sample of 388 men and women varying widely in age (18–86 years) and adiposity (BMI = 16–48 kg/m^2).

Absolute skeletal muscle mass (kg) was converted to a measure of relative muscle mass, termed skeletal muscle index (SMI), as follows:

$$\text{SMI } (kg/m^2) = \frac{\text{SMM (kg)}}{\text{height}^2 (m^2)}$$

This way, differences in SMM associated with inter-individual variation in height will be eliminated by the square of height in the denominator of the SMI.

2.2.4. Muscle performance

2.2.4.1. Handgrip strength and upper limb muscle quality. Handgrip strength (HGR) was determined using a hydraulic handgrip dynamometer (Jamar, Sammons Preston Rolyan, Bolingbrook, IL). The dynamometer was modified to each subject's dominant hand. Subjects were asked to perform a maximum strength trial ("Squeeze as hard as you can"), with each trial lasting approximately 3 s. The best of two maximal trials was registered for data analysis. Upper limb muscle quality (uMQ) was calculated as the ratio of HGR by SMM.

2.2.4.2. Knee muscle strength. Force–velocity characteristics of the knee extensors were measured using the Biodex Medical System 3® dynamometer (Biodex Medical Systems, Shirley, New York, USA) using standardized positioning of the subjects (Wijndaele et al., 2007). All measurements were performed unilateral on the right side, unless there was a medical contraindication. Three standardized tests, including isometric, speed of movement and isokinetic tests, determined the force–velocity characteristics of the knee extensors. All tests were performed twice, and the best performance was used for further analysis.

Isometric tests: static strength of the knee extensors was assessed at a knee joint angle of subsequently 120° (ISOM120°) and 90°. Subjects performed 2 maximal static knee extensions in each knee joint angle. Peak torque (Nm) of both contractions in both knee joint angles was recorded. The highest score of the extension test at 120° was kept for further analysis to assess maximal isometric knee extension strength.

Isotonic tests: subjects performed 3 maximal ballistic knee extensions against a constant load of 20% of the maximal isometric strength in a knee joint angle of 90°. They were asked to extend their leg as quickly as possible from a knee joint angle of 90–160° and then passively return the leg to the starting position (90°). Speed of movement (°/s) was recorded. The best performance of 3 repetitions was defined as the maximum speed of movement at 20% (SPEED) and was used for data analysis.

Isokinetic tests: dynamic knee extension strength was examined by conducting four maximal knee extension-flexion movements at a low velocity of 60°/s and six repetitions at a high velocity of 240°/s. Peak torque (Nm) of the knee extensions at 60°/s (ISOK60°) and at 240°/s (ISOK240°) were recorded and further analyzed.

Muscular endurance test: finally, subjects had to perform 25 knee extensions and flexions at a velocity of 180°/s. During this test total work (J) (ENDUR) was recorded as a measure of resistance to fatigue of the knee extensor and flexor muscles.

All strength measures are presented both as absolute values and relative to SMI.

2.3. Statistics

All statistical analyses were conducted using the Statistical Analysis Systems statistical software package version 9.4 (SAS Institute, Cary, NC, USA). Subjects were divided into six distinct age categories (per ten year) to compare their physical and muscle strength specific characteristics. Furthermore, SMI groups were made with cut-off points based on the SMI values of a normative young (18–30 years) adult subgroup of this study (women: $n = 49$, men: $n = 88$). Cut-off points were 1 or 2 standard deviations below the reference mean to define the low and poor group, respectively. Descriptive statistics are represented as means ± standard deviations. One way analysis of variance was used to compare age categories and SMI groups. When a difference was found, a Tukey HSD test was performed to determine which differences were significant. Sex by age category and age category by SMI group interaction effects were examined with a two-way analysis of variance. Since preceding results have shown that age and strength have a nonlinear relationship, a polynomial regression was used by including age and age^2 as independent variables (Lynch et al., 1999). Statistical significance was set at $P < 0.05$ for all analyses.

Table 1
Subject characteristics.

	Women	Men
n (range)	553–578	784–819
Age (years)	43.3 ± 10.4	45.1 ± 11.9*
Weight (kg)	65.0 ± 10.5	79.5 ± 10.8*
Height (cm)	164.6 ± 6.1	176.8 ± 6.6*
BMI (kg/m^2)	24.0 ± 3.8	25.4 ± 3.1*
FM (kg)	21.0 ± 7.1	17.1 ± 5.7*
FFM (kg)	44.0 ± 5.5	62.5 ± 7.3*
SMM (kg)	20.2 ± 2.5	31.2 ± 3.4*
SMI (kg/m^2)	7.43 ± 0.77	9.97 ± 0.89*
HGR (kg)	30.6 ± 7.7	48.4 ± 10.1*
uMQ	1.53 ± 0.38	1.56 ± 0.31

Data are means ± SD. *n*: number of subjects.
* Significantly different at $P < 0.01$.

3. Results

3.1. Subject characteristics

Characteristics of the subjects are described in Table 1. With the exception of upper limb muscle quality ($P = 0.12$), men and women were different ($P < 0.01$) for all characteristics. All the main muscle-related characteristics (FFM, SMM, SMI) were significantly higher ($P < 0.01$) in males compared to women.

Furthermore, age-group characteristics are given in Supplementary Table A1. In women, no significant difference was observed between age-groups for weight ($P = 0.16$). In men, there was no significant difference in SMI ($P = 0.39$) between age-categories.

3.2. SMI-group characteristics and frequencies

Cut-off values for the low and poor group were 9.18 kg/m^2 and 8.34 kg/m^2 in men and 6.85 kg/m^2 and 6.09 kg/m^2 in women, respectively. SMI-group frequencies according to age category are given in Fig. 1. With increasing age, there is a proportional expansion of both the low and poor group in women, especially for the poor group. In men, the expansion of the low group became apparent after the age of 40 years and was largest after the age of 70. The poor group tended to increase proportionally until 70 years, but no subjects were observed in that group thereafter. SMI-group characteristics are shown in Supplementary Table A2. No difference in FM was observed in both men and women. Moreover, in men there was no difference in age between SMI-groups. FFM and SMM were significantly higher in the normal group compared to the low and poor group in both genders. However, uMQ was the highest in the poor group compared to the low group and was still higher in the low compared to the normal group in both men ($P < 0.01$) and women ($P < 0.01$).

3.3. Outcome measurements

3.3.1. Strength performance

3.3.1.1. By age and gender. Within each age-group, men were stronger compared to women for all absolute strength measures ($P < 0.01$). One-way ANOVA's to compare age-groups separately within men and women are presented in Table 2 (men) and Table 3 (women). Two-way ANOVA's were performed to compare muscle strength characteristics between age and gender to point out

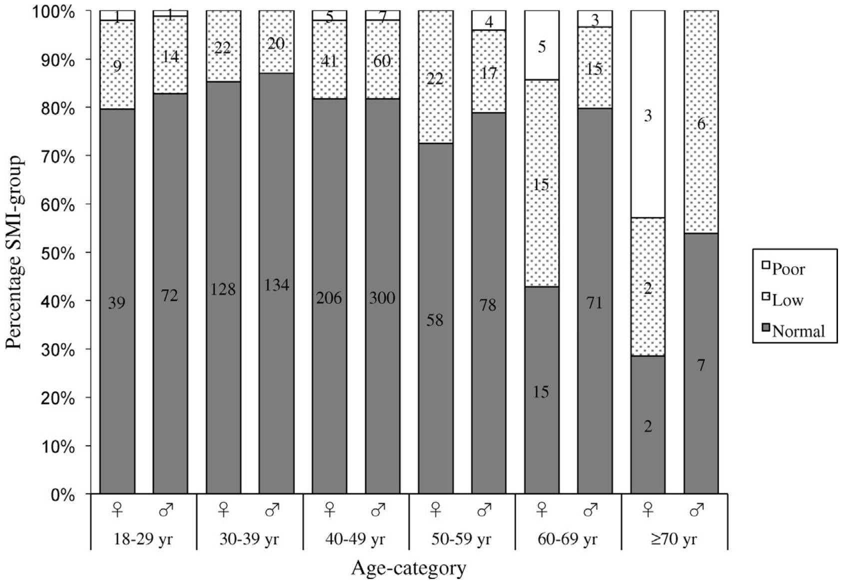

Fig. 1. SMI-group proportions according to age group in men (♂) and women (♀). Exact number of subjects included in bars.

gender-specific aging patterns. There was a significant age by gender interaction effect for absolute values of isometric strength in a knee angle of 120° ($P < 0.01$). On average, 60–70 years old men lost 12.2% of isometric strength *compared to the youngest age group*, with an additional 10% in the last decade. In females, average loss was already 21.8% at 60–70 years and increased up to 30.4% in the oldest age category (>70 years). Expressed relative to SMI, the age by gender interaction effect for isometric peak torque at 120° was no longer significant ($P = 0.14$). However, the main effect of gender remained ($P < 0.01$) and also a main effect of age was observed ($P < 0.01$). Smaller average losses were observed for this relative parameter in men (14.6% and 17.6% on average at >70 years).

Speed of movement at 20% loading (SPEED) showed a significant age × gender interaction effect ($F = 6.81$, $P < 0.01$). Aging effects compared to isometric strength were smaller as on average 9.4% and 16.7% of movement speed was lost in males, and 12.9% and 18.9% in females (by 60–70 years and >70 years, respectively). Again, SMI scaled movement speed (Rel_SPEED: $F = 0.00$, $P = 1.00$) showed no age × gender interaction. Nevertheless, a main effect of both gender ($F = 661.67$, $P < 0.01$), women showed less decrease in relative contraction speed, and age ($F = 16.69$, $P < 0.01$) remained significant.

Isokinetic strength displayed a significant interaction effect at both 60°/s ($F = 6.32$; $P < 0.01$) and 240°/s ($F = 9.68$, $P < 0.01$). This age by gender interaction effect remained significant after expression relative to SMI at both isokinetic speeds (Rel_ISOK60°: $F = 2.24$, $P = 0.0485$; Rel_ISOK240°: $F = 3.80$, $P = 0.002$). In general, overall drop in slow and faster knee extension strength was large, with 17.4–25.4% in 60–70 years old males, progressing up to 36.8% and 41% in the >70 years group, respectively. Similar values were found for the drop in relative isokinetic strength value, with less progression towards the last age group (30.5% and 35.8%, respectively). In females, larger average losses in isokinetic strength were already observed at the 60–70 years age group (28.7% and 33.5%) with a further drop for the >70 years age group (52.5% and 52.9%). For the isokinetic strength value scaled by SMI, drops were about 6% smaller by 60–70 years (22.1% and 26.7%) and about 10% by 70 years of age (43.6% and 44%), compared to the absolute isokinetic values.

Finally, muscular endurance showed a significant age × gender interaction effect ($F = 11.78$, $P < 0.01$) with the interaction effect remaining significant when endurance was scaled for SMI (Rel_ENDUR: $F = 5.00$, $P = 0.0002$). For both males and females, the total work delivered during this 25-repetition test showed the largest average drop 34.9% and 41.4 % in males and females by the age of 60–70 years, with a further average drop up to 54% and 58% for the oldest age group. Scaled by SMI, similar patterns were found.

Table 2
Strength performances in men by age group.

	18–30 years	30–40 years	40–50 years	50–60 years	60–70 years	>70 years	Age group difference	Age × gender interaction *P*-value
n (range)	86–88	152–155	360–372	97–99	87–89	13–14		
ISOM120° (Nm)	183.3 ± 46.8	185.1 ± 43.1	181.4 ± 42.1	168.6 ± 35.9	160.9 ± 40.6	141.7 ± 28.0	abc > ef; b > d*	<0.01
Rel_ISOM120° (Nm kg^{-1} m^{-1})	18.4 ± 4.7	18.6 ± 4.4	18.2 ± 4.3	17.0 ± 3.6	16.3 ± 4.0	15.7 ± 3.3	abc > e*	0.14
SPEED (°/s)	407.4 ± 42.1	414.3 ± 43.9	405.2 ± 42.6	392.3 ± 45.3	369.1 ± 45.4	339.2 ± 66.1	abc > ef; b > d; d > ef*	<0.01
Rel_SPEED (°/s kg^{-1} m^{-1})	41.0 ± 5.4	41.6 ± 5.5	40.8 ± 5.3	39.8 ± 5.7	37.6 ± 6.0	36.3 ± 8.3	abc > ef*	1.00
ISOK60° (Nm)	179.1 ± 42.9	177.7 ± 41.6	176.8 ± 40.4	156.9 ± 33.7	147.9 ± 36.8	113.2 ± 28.9	abc > def; de > f*	<0.01
Rel_ISOK60° (Nm kg^{-1} m^{-1})	18.0 ± 4.3	17.9 ± 4.4	17.8 ± 4.1	15.9 ± 3.5	15.0 ± 3.7	12.5 ± 2.8	abc > def*	0.0485
ISOK240° (Nm)	105.6 ± 24.2	103.6 ± 24.4	100.3 ± 22.1	86.6 ± 19.8	78.8 ± 20.6	62.2 ± 12.5	abc > def; d > f*	<0.01
Rel_ISOK240° (Nm kg^{-1} m^{-1})	10.6 ± 2.5	10.4 ± 2.6	10.1 ± 2.2	8.8 ± 2.0	8.0 ± 2.2	6.8 ± 1.3	abc > def; d > f*	<0.01
ENDUR (J)	3407.4 ± 653.6	3171.3 ± 756.3	3045.1 ± 677.3	2592.3 ± 654.9	2219.3 ± 650.9	1566.4 ± 448.7	abc > def; d > ef*	<0.01
Rel_ENDUR (J kg^{-1} m^{-1})	342.1 ± 66.1	318.5 ± 78.7	306.3 ± 67.9	261.9 ± 63.0	225.0 ± 64.8	171.8 ± 45.1	a > c; abc > def; d > f*	<0.01

Data are means ± SD. *n*: number of subjects. Significant ($P < 0.05$) main effects of age are denoted with *; a: age group 18–30 years, b: 30–40 years, etc.

Table 3
Strength performances in women by age group.

	18–30 years	30–40 years	40–50 years	50–60 years	60–70 years	>70 years	Age group difference	Age × gender interaction P-value
n (range)	48–49	148–152	249–251	79–81	35–37	7		
ISOM120° (Nm)	124.5 ± 31.9	123.5 ± 34.6	119.7 ± 29.0	116.2 ± 26.2	97.3 ± 25.5	86.6 ± 18.9	abc > ef; d > e*	<0.01
Rel_ISOM120° (Nm kg^{-1} m^{-1})	16.5 ± 4.6	16.4 ± 4.5	16.2 ± 4.0	15.9 ± 3.8	14.2 ± 4.0	13.6 ± 3.6	*	0.14
SPEED (°/s)	375.0 ± 41.1	376.8 ± 40.0	361.0 ± 43.8	344.8 ± 34.5	326.5 ± 40.4	303.9 ± 29.5	ab > c > def*	<0.01
Rel_SPEED (°/s kg^{-1} m^{-1})	49.8 ± 7.2	50.4 ± 6.6	49.0 ± 7.3	47.0 ± 5.8	47.7 ± 7.3	47.7 ± 7.1	b > d*	1.00
ISOK60° (Nm)	123.1 ± 27.2	119.9 ± 27.3	117.1 ± 24.2	104.3 ± 23.3	87.7 ± 23.2	58.4 ± 12.9	abc > d > ef*	<0.01
Rel_ISOK60° (Nm kg^{-1} m^{-1})	16.3 ± 3.7	15.9 ± 3.5	15.9 ± 3.4	14.3 ± 3.2	12.7 ± 3.7	9.2 ± 2.2	abc > def; d > f*	0.0485
ISOK240° (Nm)	68.4 ± 18.6	67.6 ± 15.5	64.5 ± 12.9	55.5 ± 12.0	45.5 ± 12.7	32.2 ± 4.2	abc > d > ef*	<0.01
Rel_ISOK240° (Nm kg^{-1} m^{-1})	9.0 ± 2.4	9.0 ± 2.0	8.7 ± 1.8	7.6 ± 1.7	6.6 ± 1.9	5.0 ± 0.8	abc > def; d > f*	<0.01
ENDUR (J)	2181.9 ± 508.2	1983.1 ± 495.3	1886.3 ± 428.7	1547.6 ± 424.4	1278.9 ± 326.4	913.9 ± 211.4	abc > d > e > f; a > c*	<0.01
Rel_ENDUR (J kg^{-1} m^{-1})	286.9 ± 64.3	262.7 ± 60.8	255.3 ± 58.6	212.0 ± 56.9	183.3 ± 48.0	143.6 ± 35.4	a > c; abc > def; d > f*	<0.01

Data are means ± SD. n: number of subjects. Significant ($P < 0.05$) main effects of age are denoted with *; a: age group 18–30 years, b: 30–40 years, etc.

3.3.1.2. By age and SMI. Since there were very few subjects in the poor SMI group, this group was combined with the low SMI group for the current analyses. In both men and women, there was no significant age by SMI interaction effect for any of the strength characteristics (Supplementary Table A3). Main effects for age and SMI were significant (<0.05) for all strength performance parameters, showing a decrease by age-category and a lower muscle function in the combined low group compared to the normal SMI group in both men and women. However, in men there was no main effect of SMI ($P = 0.11$) for SPEED. For example, for the group of 60–70 years, 'low SMI' females had 2.7–9.0% lower strength performance parameters compared to 'normal SMI' subjects. In males, similarly, 'low SMI' subjects showed lower strength performances (7.9–18.6%) In both males and females, largest SMI-group differences for the 60–70 years age group were observed for muscular endurance and isometric strength.

3.3.2. Quadratic age regression models

Quadratic regression analysis was performed for all absolute strength parameters. In both genders, age-associated regression patterns were significant ($P < 0.01$), with significant negative regression coefficients for the quadratic age term (Table 4). Age accounted for only up to 6% of variance in isometric strength (women: $r^2 = 0.06$; men: $r^2 = 0.05$) compared to SPEED and isokinetic strength (women: $r^2 = 0.13–0.20$; men: $r^2 = 0.11–0.16$). Furthermore, age and age^2 could explain 24% of the variance in muscular endurance in women and men.

4. Discussion

The current study aimed at describing changes during the adult life-span in muscle mass and muscle force–velocity characteristics in 819 men and 578 women of Flemish Caucasian origin. Skeletal muscle mass was estimated using a prediction formula that was previously validated by Janssen et al. (2000b). Muscle function was evaluated using a Biodex Medical System 3® dynamometer. A description was made of the distribution in Skeletal Muscle Index-groups (SMI-groups). This index has been previously used to determine whether older subjects have normal muscle, moderate sarcopenia or severe sarcopenia (Janssen et al., 2004). These cutpoints for SMI have also been associated with an increased physical disability risk (Janssen et al., 2004). Finally, muscle function was compared between SMI groups over the adult life-span.

Muscle mass parameters (FFM, SMM, SMI) were significantly higher ($P < 0.01$) in men compared to women. This is in line with previous findings showing that men exhibit a larger fat-free mass and muscle mass than women, even after adjustment for height and body weight (Gallagher et al., 1997; Janssen et al., 2000b; Lindle et al., 1997). This gender-related difference in body composition is thought to be the result of differences in sex-specific hormones (Rosenbaum & Leibel, 1999). Comparison by age and gender pointed out that there was an age by gender interaction effect for each absolute muscle function parameter, which means that men and women show different patterns of change in muscle function over age. This is contradicted by Frontera, Hughes, Lutz, and Evans (1991). They did not find interaction effects in any of the muscle groups (knee and elbow flexors and extensors) they examined (Frontera et al., 1991), however, they only compared 3 age-groups, ranging from 45 to 78 years. Lindle et al. (1997) examined isometric, concentric and eccentric peak torque of the knee extensors and found, similar to our results, significant age-by-gender interactions for all muscle actions and velocities in the four age-categories they examined (Lindle et al., 1997). The reported average drop in concentric strength (women: 35%; men: 33%) by Lindle et al. (1997) was smaller than the average drop observed in our study (women: 52.5%; men: 36.8%). Quadratic regression analysis pointed out that isometric strength was less influenced by age than speed of movement or isokinetic speed (Table 4). Furthermore, muscular endurance was most influenced by age in both women and men ($r^2 = 0.24$).

In general, overall drop in slow and faster knee extension strength was larger than the isometric component, with women showing larger losses by the age of 60–70 years compared to men. This observation has been found in several other studies and might

Table 4
Quadratic age regression models.

	Women			
	Intercept	Age	Age^2	r^2
ISOM120°	113.1	0.93 (n.s.)	−0.02	0.06
SPEED	370.4	1.06 (n.s.)	−0.03	0.13
ISOK60°	106.8	1.31	−0.03	0.15
ISOK240°	60.2	0.77	−0.02	0.20
ENDUR	2299.1	2.94 (n.s.)	−0.30	0.24

	Men			
	Intercept	Age	Age^2	r^2
ISOM120°	164.0	1.45	−0.02	0.05
SPEED	373.5	2.51	−0.04	0.11
ISOK60°	140.2	2.47	−0.04	0.10
ISOK240°	88.5	1.23	−0.02	0.16
ENDUR	2920.0	34.5	−0.71	0.24

Data are b-coefficients.

be related to the age-related decrease in fiber size of type II fibers in particular (Lexell, Taylor, & Sjostrom, 1988). Largest average losses were observed for the muscular endurance test. Although similar fatigue profiles have been observed for intermittent submaximal isometric fatigue tests between young and old (Mcphee, Maden-Wilkinson, Narici, Jones, & Degens, 2014), the test used in our study represents a maximal test, in which the age-related drop in overall work represents in part the accumulative effect of lower torques for each repetition, together with a possible drop in sustainable maximal strength when the muscle is fatigued.

However, the age × gender interaction effects were somewhat different when they were scaled relative to SMI (muscle quality measures). Interaction effects were no longer significant for both isometric strength (Rel_ISOM120°) and speed of movement (Rel_Speed), although a main effect of gender and age remained. This indicates that men and women show a similarity in the pattern of changes in relative isometric strength and speed of movement with increasing age. This was previously found for leg muscle quality, but not for shoulder strength normalized to SMM (Alizadehkhaiyat, Hawkes, Kemp, Howard, & Frostick, 2014; Lynch et al., 1999). Nevertheless, interaction effects remained significant when dynamic strength at both speeds was expressed relative to SMI (Rel_ISOM60°: $P < 0.01$ and Rel_ISOM240°: $P < 0.01$). This was also the case for strength endurance scaled to SMI (Rel_ENDUR: $P < 0.01$). These findings indicate a faster decrease with ageing in women for dynamic strength and endurance strength expressed relative to SMI.

The European Working Group on Sarcopenia in Older People (EWGSOP) suggested the use of a normative (healthy young adults) reference population to determine cut-off points for sarcopenia (Cruz-Jentoft et al., 2010). These should be set at respectively 1 and 2 standard deviations beneath the mean reference value. This practice has already been implemented by Baumgartner et al. (1998) to define sarcopenia via the use of a skeletal muscle index (appendicular skeletal muscle mass/height^2) (Baumgartner et al., 1998). Defined in this way, they reported a significant association between self-reported physical disability in both men and women, independent of ethnicity, age, morbidity, obesity, income and health behaviors (Baumgartner et al., 1998). In 2002, Janssen et al. defined SMI (skeletal muscle mass/body mass × 100) cutpoints to establish the prevalence of sarcopenia and to test the hypothesis that sarcopenia is related to functional impairment and physical disability in older persons (Janssen et al., 2002). They found that the likelihood of functional impairment and disability was ~2 times greater in the older men and ~3 times greater in the older women with class II sarcopenia (=SMI below − 2 SD of young adult values).

In the current study we determined cut-off values based on a normative subgroup of 18–30 years old healthy subjects (men: $n = 88$; women: $n = 49$). This way, we defined a normal, low and poor skeletal muscle index (skeletal muscle mass/height^2) group based on the mean and standard deviation of this normative reference group. Subjects of the normal group had a SMI of at least 9.18 kg/m^2 in men and 6.85 kg/m^2 in women. SMI cutpoints of 9.18–8.34 kg/m^2 and ≤8.34 kg/m^2 were selected to denote low and poor SMI in men. In women, these values were respectively, 6.85–6.09 kg/m^2 and ≤6.09 kg/m^2. These cut-off values are similar to the ones found in the study of Janssen et al. (2004). These researchers found SMI cutpoints of 5.76–6.75 kg/m^2 and ≤5.75 kg/m^2 to denote moderate and high physical disability risk in women. In men, corresponding values were 8.51–10.75 kg/m^2 and 8.50 kg/m^2 (Janssen et al., 2004).

With increasing age, a proportional expansion of both the low and poor group was found in our study population. In women, this age-related expansion became even larger in the poor group compared to the low group. The cut-off values described here can therefore be useful to diagnose subjects at risk for physical disability. Age by SMI interactions were examined in women and men separately for all muscle function parameters, but none were significant. Pointing out that there are no significant differences in the pattern of muscle function decline between SMI groups (normal vs. low + poor) over the adult life-span. Main effects of age and SMI were significant however. With increasing age, a decrease in muscle function was apparent and subjects with a normal SMI had a better muscle performance compared to subjects in the low SMI category. In men however, there was no significant main effect of SMI for SPEED. To the best of our knowledge, there is currently no study that has examined muscle function between SMI groups. We found a negative effect of belonging to a low SMI category on muscle function.

It is important to recognize that the present study has some limitations. First, our study design was cross-sectional, and therefore, causal inferences cannot be established. Drop or progression in loss of muscular strength need therefore to be interpreted as differences between age groups, rather than longitudinal decreases. It also should be considered that a cross-sectional design can be influenced by secular changes, intergenerational differences representing changes in the population characteristics (Mitchell et al., 2012). Second, there was no assessment of parameters that may influence the relationship between muscle mass and muscle function, such as protein intake, physical (in-) activity or training status. These parameters have previously been shown to influence muscle mass and/or muscle function (Volpi, Nazemi, & Fujita, 2004). Finally, it should be noted that using indirect methods to assess human body composition, such as BIA, inherently include prediction errors. In the case of BIA, the standard error of the estimate for predicting muscle mass is about 9 percent (Janssen et al., 2000a). Nevertheless, bio-electrical impedance is a valid method and due to its practicality and low cost it is very useful in the field (Lukaski, Bolonchuk, Hall, & Siders, 1986). This estimation error may have led to misclassification based on the skeletal muscle mass index (SMI). Also the SMI can be seen as a total body index – amount of muscle mass for height-parallel to the BMI as a measure of total mass for height. More regional measures of muscle cross-sectional area might therefore be better to study muscle quality characteristics for the specific knee strength characteristics.

Future research should aim at examining the relation between muscle mass and muscle strength via longitudinal research and try to account for the effect of changes in physical activity and nutrition. It will also be important to examine the influence of intrinsic sex-related differences in skeletal muscle properties to further clarify the cause of this gender difference in muscle strength and function. Furthermore, although it is widely recognized that genetics have an important influence on skeletal muscle mass and function, so far most research has focused on the effects of environmental factors such as nutrition and physical activity (Tan, Liu, Lei, Papasian, & Deng, 2012). Further research therefore is necessary to determine the relation between genetic sequence variation and variation in muscle mass and muscle function. This way strategies can be developed to target subjects at risk for sarcopenia and interventions can be designed to make concessions to the specific needs of these subjects.

Based on the results we derived in the current study, reference values can be found for muscle strength parameters in healthy, Flemish Caucasians by age and gender. An age by gender interaction effect was found for each muscle function parameter, pointing out a stronger age-related decline in muscle function in women compared to men. These interaction effects were no longer significant for isometric strength and speed of movement when expressed relative to SMI. Main effects of age and gender however persisted indicating that isometric strength scaled to SMI was higher in men compared to women and Rel_SPEED was higher in women compared to men. Both relative parameters decreased significantly with ageing pointing towards changes in muscle quality by aging. An age by gender interaction effect remained for SMI scaled isokinetic strength and strength endurance. The current study also established SMI cut-off values in Flemish Caucasians. Furthermore, we observed a proportional increase of low and poor SMI group frequencies over the entire adult-life span. The increased frequency of the poor group with ageing indicates the importance for research on the association of SMI with physical disability, although the pattern of change in muscle function was not significantly different between SMI groups. However a low SMI results in a weaker muscle function compared to a normal SMI in each age-category and its relationship with physical disability should therefore be further examined over the adult life-span.

Conflict of interest

None.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.archger.2015.06.009.

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