Predicting fat-free mass index and sarcopenia: A pilot study in community-dwelling older adults

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Received: 18 July 2012 / Accepted: 27 December 2012 / Published online: 16 January 2013
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Abstract Age-related muscle loss, termed sarcopenia, has been linked to an increased risk of falls, disability, and mortality. The purpose of this study was to develop a predictive measurement tool to estimate normalized fat-free mass index (FFMI), a means of identifying sarcopenia, in community-dwelling older adults. Functionally relevant measurements including mobility tests, food records, circumference measures, balance, and gait variables were included to ensure this model was comprehensive and accessible to clinicians. Eighty-five community-dwelling older adults (42 male) aged 75.2 ± 5.7 years participated. Each completed two questionnaires regarding general health and physical activity levels. Anthropometric, strength, balance, gait, nutrition, and body composition tests were then conducted. A fat-free mass value, determined by bioelectrical impedance analysis, was normalized by height (FFMI). FFMI along with grip strength and gait speed was used

to classify sarcopenia. FFMI was significantly correlated with all circumference measures (waist, arm, calf, and thigh) and body mass index (BMI), but no nutritional parameters. In males, maximum grip strength and a novel quiet balance measure, time outside of a 95 % confidence ellipse (TOE), were both positively correlated to FFMI. In females, age and double-support time correlated to FFMI. The prediction equation that accounted for the most variability of FFMI included the independent variables: sex, step time, BMI, and TOE (adjusted $R^2=0.9272$). The proposed linear regression model can successfully predict FFMI values to a high level of accuracy in men and women. With this information, sarcopenia can be predicted by clinicians, and early interventions can be planned and implemented.

Keywords Sarcopenia · Community-dwelling older adults · Gait · Balance · Fat-free mass index (FFMI) · Bioelectrical impedance analysis (BIA)

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Introduction

Sarcopenia is becoming an important issue in North America due to a rapidly growing older adult population. This age-related muscle loss has been linked to an increased risk of falls, which is a major concern for older adults due to the disability and mortality rates associated with falling (Roubenoff 2000). Sarcopenia

is characterized by a progressive loss of muscle which begins as early as the fourth decade of life (Waters et al. 2000). Though it is not a linear relationship, the decrease in muscle is related to a decrease in function and strength (Janssen et al. 2002). Many factors such as motor unit loss (Doherty et al. 1993), declines in mitochondrial biogenesis (Marzetti et al. 2010), and inflammation (Payette et al. 2003) are thought to perpetuate the loss of muscle throughout the aging process, though the exact mechanisms are not fully understood.

Although the presence of sarcopenia can be detected by using body composition devices that measure fat-free mass, these anthropometric measures alone do not provide information about functional deficits related to the loss of muscle mass. Recently, the European Working Group on Sarcopenia in Older People (EWGSOP) has agreed on a method for identifying older adults with sarcopenia (Cruz-Jentoft et al. 2010). Their proposed model uses gait speed (<0.8 m/s) followed by hand grip strength (values are dependent on body mass index (BMI), though approximately <30 kg men, <20 kg women) and body composition analysis (decreased muscle mass in reference to a healthy young population) to classify these individuals. While this technique has become the recent standard in targeting individuals who require clinical intervention, it is important to note that the tool identifies older adults who already have functional impairments. It has been suggested that “at risk” patients should be assessed with this technique; however, these patients were already deemed non-ambulatory or incapable of rising from a chair unassisted (Fielding et al. 2011). Thus, while this definition may accurately identify older adults with marked mobility impairments, it may not be sensitive enough to predict the start of subtle functional impairments. As sarcopenia is a progressive condition, it is necessary to have a model that is able to predict low muscle mass and related changes before the onset of motor impairments. Access to a validated and reliable predictive criterion would facilitate early screening and detection of sarcopenia before individuals are considered at risk. Once identified, early interventions could be implemented to attenuate the progression of sarcopenia with the goal of decreasing falls and improving quality of life.

The *main objective* of this study was to validate and expand on a previous model developed in a small sample of older adults ($n=33$) by our lab (Krause et al. 2011) and determine the best predictors of fat-free

mass index (FFMI). In addition, the incorporation of the EWGSOP's new classification of sarcopenia, the current gold standard, into the study was of interest to us while moving forward in this expanding field. Our previous model (Krause et al. 2011) was the first attempt to characterize low muscle mass in a small group of older adults living in the community as well as individuals residing in an assisted-living facility. To streamline our model, we removed two clinical tests and added a nutritional assessment component; we also chose to restrict our sample size for validation of our model to *community-dwelling* individuals. The initial study used the Dynamic Gait Index (DGI) in conjunction with the Berg Balance Scale and the Timed Up and Go test, and each of these tests was strongly correlated with each other. To improve data collection efficiency in this validation study, we elected to modify the protocol and include only one clinical test (DGI) which is designed to assess functional balance and gait during eight different adaptive locomotor tasks (e.g., obstacle avoidance, stairs). Adequate nutrition is thought to play a key role in the progression of sarcopenia; therefore, a 3-day food record was used to investigate potential relationships between diet and fat-free mass. Ingested protein provides amino acids which are necessary for muscle protein synthesis (Kim et al. 2010). In addition to protein, vitamin D receptors have been linked to muscle strength (Geusens et al. 1997). For numerous reasons, including social and sensory changes (Robinson et al. 2012), food intake declines with age; therefore it was also of interest to examine total calories consumed as well as a breakdown of these macronutrients.

In the current study, the examined predictors were based on anthropometric, strength, nutrition, balance, and gait measures in a larger population ($n=85$) of healthy community-dwelling older adults. A measure of fat-free mass normalized by height [FFM (kilograms)/height² (square meters)] was compared to a young population (Schutz et al. 2002) and used to classify sarcopenia along with grip strength and gait speed using the cutoff values published by the EWGSOP (Cruz-Jentoft et al. 2010). It was hypothesized that grip strength, waist circumference, double-support time variability within the gait cycle, and anterior–posterior sway variability would all be related to FFMI, as suggested by our previous work in this area (Krause et al. 2011). In addition to the above factors, it was predicted that protein intake would be correlated with FFMI, as it

has been implicated in muscle regulation (Loenneke and Pujol 2011; Lord et al. 2007).

Methods

Participants

Eighty-five community-dwelling older adults residing in the city of Guelph (42 male, 43 female), aged 75.2 ± 5.7 years, provided informed consent for participation in this study. A priori power analysis was conducted before the study (G*power) which estimated that a sample size of 80 individuals would achieve adequate power to support the current hypotheses. All older adults completed a phone screening before participation to ensure they were at least 65 years of age and able to walk 18 m, stand for 1 min unassisted, and perform activities of daily living independently. The phone screening also determined whether the participant had a pacemaker or any congestive heart or kidney conditions. These exclusion criteria were set in place due to the conductive nature of the bioelectrical impedance analysis test. This study was reviewed and approved by the Research Ethics Board at the University of Guelph.

Questionnaires

At the beginning of testing, all participants completed a self-reported general information and health questionnaire to gather sociological data and address any possible health concerns. Next, the participants completed a Mini Mental Status Exam (MMSE) (Folstein et al. 1975) to assess cognition. All participants achieved a score of at least 25 (of a possible 30), which was the minimum score necessary to participate in the study (set by Research Ethics Board). Informed consent was then completed, followed by the Physical Activity Scale for the Elderly (PASE) to provide a single score to quantify the level of general daily activities (Washburn et al. 1993).

Anthropometric measurements

Participants were asked to remove their footwear while their height and weight were measured. Using a standard measuring tape, waist circumference, mid-arm circumference, mid-calf circumference, mid-thigh

circumference, and leg length (measured from the greater trochanter to the floor) were recorded.

Body composition

Bioelectrical impedance analysis (BIA) was used for all of the body composition measures for its portability, efficiency, and cost-effectiveness. A two-compartmental model of fat mass (FM) and fat-free mass (FFM) was measured for all participants using BIA (model 1500, Bodystat, Douglas, Isle of Man) which is based on conductance and impedance of tissues within the body. Since the conductance of fat mass and fat-free mass differ, an impedance value can be obtained and used to estimate these mass distributions (National Institutes of Health Technology 1996). This technique has often been used by others (Janssen et al. 2002, 2004a, b; Krause et al. 2011; Castillo et al. 2003) in the assessment of muscle mass and was critical within this project to enable the collection of a larger sample of older adults. Our BIA procedure was detailed to control for possible variation. To ensure proper hydration status, all participants were instructed to: drink at least two glasses of water, not to participate in any strenuous exercise, not to eat a large meal or drink excessive caffeine 12 h before, and not to consume alcohol 24 h before the session. Participants voided their bladder then lay supine with limbs abducted so they were not touching their torso for at least 4–5 min. Following this, two medi-trace electrodes (model 130; Kendall, MA, USA) were placed on both the right hand and right foot. Cables were then attached from the BIA device to the electrodes. Impedance was measured (coefficient of variation=16 %) and then using the equation provided by the device, FM and FFM were calculated (kilograms) for each participant.

Biomechanical and clinical tests

Isometric handgrip strength testing was completed using a portable Vernier digital hand dynamometer and collected using LoggerPro software (Vernier, OR, USA; 60 Hz). All subjects were asked to stand with their arms close to their thorax and elbows bent at a 90° angle when squeezing the dynamometer. Participants were given visual feedback and verbal encouragement throughout each trial. Peak forces (Newtons) from six trials (three per hand) were then completed. The peak force, regardless of hand dominance, was recorded and used to represent the subject's maximum handgrip strength.

Gait was measured using a 7-m GAITRite mat system (50 Hz; CIR Systems, PA, USA). To ensure steady-state gait, participants walked an additional 2 m before and after the mat during five self-paced trials (Kressig et al. 2006).

Each participant also completed the DGI to obtain a single scored value used for clinical assessment. This series of eight walking tasks was designed to examine recovery from perturbations and transitions (Herman et al. 2009).

Balance was measured using an AccuGait portable force platform (50 Hz; AMTI, MA, USA). Participants were asked to remove their footwear and stand quietly staring at a target placed at eye level on the wall in front of them. Foot tracings were used to ensure similarity of foot placement between trials. Three, 1-min trials were conducted with the participant sitting and resting between trials.

Acquisition of nutritional information

Following the data collection session of data collection, participants were asked to complete a multiple-day food record (version 3; Fred Hutchinson, WA, USA). Eighty-three of the 85 food records were returned (~98 % return rate). Participants were instructed to give a detailed description of the food and beverages consumed (brand, portion size, meal) and location of meal (home, restaurant, other) over a 3-day period which included two consecutive weekdays and 1 day on the weekend.

Data analyses

Biomechanical data analysis

The first and last footfalls were eliminated from each GAITRite trial to remove any partial footfalls and changes in velocity due to transitioning on and off the mat. For each trial, the means and standard deviations of speed (meters per second), cadence (steps per minute), and speed normalized to each participants' leg length (NS; seconds⁻¹) were calculated. Means and standard deviations of additional spatiotemporal measures, including step length (centimeters), step time (seconds), stride length (centimeters), stride time (seconds), double-support time (seconds), and single-support time (seconds), were then analyzed. Finally, the mean standard deviation (mean SD) and standard deviation of the

standard deviation (SD of SD) were also calculated to provide insight into step-to-step gait variability.

Force plate data were filtered at 10 Hz using a dual low-pass second-order Butterworth filter. The first and last 5 s were removed from each trial to capture steady quiet standing, and the remaining 50 s was analyzed. Center of Pressure (COP) was then calculated (Reed-Jones et al. 2008) and normalized according to the mean COP excursion value in both the medial–lateral and anterior–posterior directions. Mean anterior–posterior and medial–lateral ranges, velocities, and accelerations, and cumulative path lengths were all calculated. Cumulative path length is a sum of all of the displacement that occurred throughout the trial (Collins and De Luca. 1993; Winter. 1995). In addition to the standard quiet standing measures used, further analysis were performed in order to characterize brief periods of instability. A novel measure, time spent outside a 95 % confidence ellipse area (TOE), was used to serve this purpose. This calculation enabled the examination of brief moments during a trial that were unique to each individual to allow for a different calculation of each participant's variability. This is arguably a more sensitive measure than a root mean square analysis, as these brief periods might be masked if only an average was taken. In addition to TOE, the frequency of excursions, as well as total displacement and velocity when traveling outside of the 95 % confidence ellipse, was calculated. TOE was calculated using the following equations along with the COP data.¹

$$\text{COP}\theta = \tan^{-1} \frac{(\text{COP}_{\text{AP}} - \bar{\text{COP}}_{\text{AP}})}{(\text{COP}_{\text{ML}} - \bar{\text{COP}}_{\text{ML}})} \quad (1)$$

$$\text{Ellipse} = \frac{\text{SD.COP}_{\text{ML}} \times 2 \times \text{SD.COP}_{\text{AP}} \times 2}{\sqrt{(2 \times \text{SD.COP}_{\text{ML}} \times \sin(\text{COP}\theta))^2 + (2 \times \text{SD.COP}_{\text{AP}} \times \cos(\text{COP}\theta))^2}} \quad (2)$$

Thus, the times when the COP radius was outside the above ellipse were recorded and summed to obtain the total time outside the 95 % confidence ellipse (TOE). In addition to the means, the standard deviations and SD of SD were calculated for each measure to facilitate the examination of the variability between and within trials.

¹ If COP_{ML} was less than zero, then π was added to the $\text{COP}\theta$ calculation.

Nutritional data analysis

Information collected from the multiple-day food record was entered into the Food Processor® SQL-ESHA database version 10.8.0 (ESHA Research, Salem, OR, USA). Unless otherwise indicated, each portion size was allocated as one serving of the Canadian standard or US Department of Agriculture. The food records were used to investigate the relationships between nutrients and muscle quantity. Protein, carbohydrates, fat, and vitamin D were all variables of interest that were included in statistical analysis. As protein was the major macronutrient of interest, it was normalized both by intake according to body mass and by total caloric intake to examine possible relationships with FFMI.

Defining sarcopenia

FFMI was calculated using the following formula:

$$\text{FFMI}(\text{kg}/\text{m}^2) = \text{fat-free mass}(\text{kg})/\text{height}^2(\text{m}^2) \quad (3)$$

Participants with a FFMI two standard deviations below a young-adult reference population reported by Schutz et al. in 2002 were designated to be pre-sarcopenic (as adapted from Janssen et al. in 2002). If these participants also had a gait speed less than 0.8 m/s or hand grip strength less than the cutoff specified by EWGSOP according to BMI (approximately 30 kg for men or 20 kg for women), then they were classified as sarcopenic, and if they had both, they were identified as severely sarcopenic (Cruz-Jentoft et al. 2010). Participants that had muscle mass 1–2 SD lower than the reference population were reported as having class I low muscle.

Statistical analyses

Statistical analyses were conducted using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). Relationships between FFMI and possible predictive factors (e.g., biomechanical, clinical, anthropometrics, nutritional variables) were explored using Pearson's correlation coefficients. Data were separated to examine possible sex differences, as it has been shown that men and women are affected differently by falls (Web-based Injury Statistics Query and Reporting System, 2011). As falls have been linked to sarcopenia (Roubenoff, 2000), it was of interest to examine population

relationships as well as sex differences. These relationships were shown using Pearson's correlation coefficients and Student's *t* tests ($p < 0.05$). The data were then randomly partitioned into two groups: the prediction group ($n = 57$, 27 M/30 F) from which the regression analysis was performed on and a validation group ($n = 28$, 15 M/13 F) which was then used to cross validate the model. Stepwise forward and backward regressions were performed on the prediction group, and multicollinearity was assessed. In the final model, the variance inflation factors of each independent variable were less than 1.5. The residuals were normally distributed (Shapiro–Wilk test); they summed to zero and were heterogeneous and random. The significance for all statistical analyses was set at $\alpha = 0.05$.

Results

Subject characteristics and average results for clinical and biomechanical measures are outlined in Tables 1 and 2. From the questionnaires, it was revealed that 63 (74 %) of our participants had at least some university or college education, and all but six (93 %) completed high school. None of the participants reported neurological or musculoskeletal diseases during the general health questionnaire. More than half of our participants had lower than normal grip strength (as stratified by BMI via EWGSOP). In our experimental population, 5 out of 85 individuals (three female and two male) were classified as sarcopenic (see Table 3). In addition, three other females were deemed pre-sarcopenic, as their muscle mass was 2 SD lower than the reference population, yet they had no decrease in function or strength. Nine other older adults were considered to have class I muscle loss (muscle mass 1–2 SD below reference population), who, in addition, had low grip strength. Correlation coefficients are listed in Table 4 for the full sample population, as well as split between males and females. Fat-free mass index was significantly correlated with all circumference measures (waist, arm, calf, and thigh). FFMI was also correlated to sex, grip strength, BMI, and TOE. Several gait cycle parameters were correlated to FFMI including: cadence, step length, stride length, stride time, swing time, stance time, single-support time, and double-support time. FFMI was not correlated to the frequency of excursions or the total displacement outside of the ellipse; however, displacement and time

Table 1 General participant characteristics divided by sex

Characteristics Mean (SD); range	Male (<i>n</i> =42) <i>n</i> =41 for nutrition measures	Female (<i>n</i> =43) <i>n</i> =42 for nutrition measures
Age (years)	76.2 (6.0) Range, 65–87	74.2 (5.3) Range, 66–89
Mini Mental Status Exam (MMSE)	28.9 (1.0) Range, 25–30	29.1 (0.9) Range, 26–30
Physical Activity Scale for the Elderly (PASE)	139.3 (57.5) Range, 24.8–288.2	146.8 (68.6) Range, 17.9–391.9
Dynamic Gait Index (DGI)	21.5 (2.6) Range, 14–24	21.7 (2.3) Range, 15–24
Height (cm)*	175.6 (5.1) Range, 165–189	160.1 (6.9) Range, 142.5–177
Weight (kg)*	79.4 (10.6) Range, 64.1–110.9	64.1 (10.2) Range, 46.4–95.5
BMI (kg/m ²)	25.5 (3.7) Range, 14.2–33.2	25.0 (3.9) Range, 18.2–34.7
Waist circumference (cm)*	97.7 (8.7) Range, 81–121	89.5 (9.1) Range, 75.6–117
Arm Circumference (cm)	29.8 (3.3) Range, 23–41	28.7 (3.7) Range, 22–37.5
Calf circumference (cm)	36.7 (2.5) Range, 31–42.5	36.2 (4.2) Range, 27.5–50.5
Thigh circumference (cm)	49.7 (4.6) Range, 41.5–61	51.8 (7.3) Range, 32.5–71.5
Maximum handgrip (kg)*	27.4 (5.8) Range, 17.9–39.6	16.4 (4.0) Range, 8.2–24.1
Fat mass (kg)*	21.2 (5.7) Range, 11.8–37.2	26.1 (6.3) Range, 17.4–48.4
Fat mass (%)*	26.5 (4.2) Range, 16.3–37.2	40.2 (4.7) Range, 31.1–51.2
Fat-free mass (kg)*	57.7 (6.8) Range, 48.2–76.2	38.4 (5.5) Range, 27.3–48.9
Fat-free mass (%)*	73.5 (4.2) Range, 62.8–83.7	59.8 (4.7) Range, 48.8–68.9
Average caloric intake (kcal)*	2,182 (578) Range, 1,048–3,572	1,918 (573) Range, 1,102–3,623
Protein (g)	85.83 (28.18) Range, 41.29–165.60	79.63 (23.45) Range, 34.22–135.72
Protein intake normalized by body weight (g/kg)	1.27 (0.40) Range, 0.45–2.17	1.10 (0.42) Range, 0.51–2.26
Protein intake normalized by total calories (%)	16.2 (4.3) Range, 9.4–31.1	17.1 (3.7) Range, 10.2–25.6
Fat (g)	76.82 (31.83) Range, 26.65–158.76	70.64 (25.02) Range, 31.71–123.21
Carbohydrates (g)*	282.35 (95.10) Range, 118.71–490.38	239.57 (88.67) Range, 135.49–508.92
Vitamin D (μg)	4.34 (3.07) Range, 0.39–13.85	5.01 (4.26) Range, 0.48–17.23
FFMI (kg/m ²)*	18.7 (1.9) Range, (15.2–22.8)	14.8 (1.8) Range, (10.9–17.9)

**p*<0.05 indicating a significant difference between males and females as determined using Student's *t* test

Table 2 Gait and balance measures divided by sex

Gait and balance characteristics (mean±SD range)	Male (n=42)	Female (n=43)
Gait parameters		
Cadence (steps/min)*	111.9 (8.1)	123.2 (7.9)
Gait speed (m/s)	1.4 (0.2)	1.4(0.2)
	Range, 1.0–1.8	Range, 1.0–1.9
Gait speed normalized to mean leg length (s ⁻¹)*	1.5 (0.2)	1.6 (0.2)
	Range, 0.92–2.0	Range, 1.17–2.1
Step length (cm)*	76.7 (8.0)	68.2 (7.2)
	Range, 62.2–101.4	Range, 52.4–84.8
Stride length (cm)*	153.5 (16.0)	136.5 (14.4)
	Range, 125.1–203.6	Range, 105.2–170.3
Step time (s)*	0.54 (0.04)	0.49 (0.03)
	Range, 0.47–0.67	Range, 0.42–0.60
Stride time (s)*	1.08 (0.08)	0.98 (0.07)
	Range, 0.93–1.34	Range, 0.86–1.19
Swing time (% GC)*	41.1 (2.9)	37.7 (2.0)
	Range, 35.0–48.0	Range, 34.4–42.6
Stance time (% GC)*	67.0 (5.7)	60.1 (5.1)
	Range, 56.4–86.5	Range, 51.0–77.0
Single-support time (% GC)*	41.2 (2.8)	37.7 (1.9)
	Range, 35.1–48.2	Range, 35.1–48.3
Double-support time*	26.0 (4.0)	22.8 (3.9)
	Range, 19.1–38.2	Range, 15.7–34.8
Stride velocity	143.3 (19.5)	140.6 (20.1)
	Range, 95.7–194.6	Range, 95.9–189.8
Balance parameters		
Cumulative path length (cm)	63.3 (19.2)	55.5 (18.8)
	Range, 31.1–110.4	Range, 31.4–153.4
Total sway velocity (cm/s)	0.12 (0.04)	0.11 (0.04)
	Range, 0.06–0.22	Range, 0.06–0.31
Medial–lateral range (cm)*	1.67 (0.69)	1.36 (0.54)
	Range, 0.68–3.76	Range, 0.55–2.79
Anterior–posterior range (cm)*	2.91 (0.84)	2.31 (0.58)
	Range, 1.74–5.03	Range, 1.57–4.12
Time outside ellipse (s)	6.5 (0.7)	6.4 (0.6)
	Range, 4.8–8.3	Range, 4.9–7.8
Frequency of excursions outside the 95 % confidence ellipse (all 3 trials)	41 (15)	44 (14)
	Range, 19–76	Range, 22–89
Average displacement (cm) outside of 95 % confidence ellipse*	6.20 (1.86)	5.28 (2.04)
	Range, 2.88–11.85	Range, 2.45–14.75

* $p < 0.05$ indicating a significant difference between males and females as determined using Student's t test

were positively correlated. Results from the physical activity to scale for the elderly were not correlated to FFMI and nor were any of the diet-related variables

that were examined. Sex was negatively correlated, indicating that women had significantly smaller FFMI than men. Maximum handgrip strength was correlated

Table 3 Sarcopenic classifications of the population used for this study; classifications were based on the EWGSOP model, using the reference population from Schutz et al. (2002)

Sex	Low gait speed	Low grip strength categorized by BMI	Class I low muscle	Pre-sarcopenic (class II low muscle)	Class I low muscle+low grip strength	Sarcopenic	Severely sarcopenic
Male, <i>n</i> (%)	1 (1 %)	31 (74 %)	4 (10 %)	0 (0 %)	4 (10 %)	2 (5 %)	0 (0 %)
Female, <i>n</i> (%)	0 (0 %)	26 (60 %)	11 (26 %)	3 (7 %)	5 (12 %)	3 (7 %)	0 (0 %)

with FFMI only in males, while double-support time and age were correlated with FFMI only in females.

$$\begin{aligned} \text{FFMI} = & 12.104 + (0.394 \times \text{BMI}) \\ & - (3.876 \times \text{sex}) - (7.131 \times \text{step time}) \\ & + (0.616 \times \text{TOE}) \end{aligned} \quad (4)$$

The prediction equation (Eq. 4) that accounted for the most variability of FFMI included sex (where male=1, female=2), TOE, BMI, and step time (adjusted $R^2=$

Table 4 Results from a Pearson correlation analysis; values in bold represent correlations between FFMI and measured variables with $p<0.05$ (negative correlation values signify that women have lower fat-free mass indices than men)

	FFMI (population)	FFMI (men, <i>n</i> =42)	FFMI (women, <i>n</i> =43)
Sex	-0.752	N/A	N/A
Age	-0.061	-0.235	-0.372
WC	0.715	0.767	0.561
ArmC	0.617	0.669	0.862
CalfC	0.506	0.801	0.659
ThighC	0.295	0.685	0.669
MaxGRip	0.696	0.326	0.285
BMI	0.594	0.788	0.886
TOE	0.278	0.373	0.205
Cadence	-0.477	-0.100	-0.045
Step length	0.355	-0.108	0.064
Step time	0.472	0.120	0.041
Swing time	0.352	-0.098	-0.264
Stance time	0.521	0.214	0.199
Single-support time	0.352	-0.107	-0.256
Double-support time	0.503	0.363	0.347
Normalized protein	-0.412	-0.340	-0.470

0.9272 for the prediction group, 0.8271 for the validation group; see Fig. 1 for the predicted versus measured FFMI values and Table 5 for regression information). The regression equation from our past study was applied to these data; however, the adjusted $R^2=0.6850$ was slightly less than the $R^2=0.707$ obtained from the previous sample population which included individuals residing both in the community and in an assisted-living facility.

Discussion

Body composition measurements revealed that 6 % of the study population were classified as sarcopenic. This is lower than other findings in the literature that range anywhere from 11 to 52 % in adults 65 and older (Fielding et al. 2011). This variability could result from the various definitions of sarcopenia. For example, the current study defined sarcopenia using FFMI, while a model by Janssen et al (2002) used the skeletal

Fig. 1 Acquired prediction model using multiple linear regression analysis with the variables BMI, sex, step time, and time outside 95 % confidence ellipse; the population was divided into a prediction group (circles; adj. $R^2=0.9272$) to make the model and a validation group (plus signs; adj. $R^2=0.8271$) to verify the predictability of the proposed model

Table 5 Statistical results of the multiple linear regression prediction model ($n=57$), conducted in SAS version 9.3 (SAS Institute Inc., Cary, NC, USA); the model was statistically significant at $p<0.05$

Variable	<i>DF</i>	Parameter estimate	Standard error	β value	$\text{Pr}> t $	Variance inflation factor
Intercept	1	12.104	2.1488	0	<0.0001	0
Sex	1	−3.876	0.2216	−0.75	<0.0001	1.407
Body mass index	1	0.394	0.0266	0.55	<0.0001	1.053
Time outside a 95 % ellipse	1	0.616	0.1734	0.13	0.0008	1.101
Step time	1	−7.131	2.9956	−0.10	0.021	1.354

muscle mass index (SMI). Using SMI to define sarcopenia is better for predicting sarcopenic obesity since it is representative of the percentage of muscle mass; however, that model is more likely to include false positives in classifying sarcopenia since they also include anyone 1–2 standard deviations below a young reference population (class I). The older adults in the current study were all completely independent and mobile, living within the community in Guelph. The purpose of this study was to determine the best predictors of FFMI in a community-dwelling population and to validate a model presented previously by our lab group (Krause et al. 2011). The original regression model included waist circumference, grip strength, double-support time, and the variability of sway range in the sagittal plane. When applied to the current population, the predictability of the variation of FFMI decreased by 5.7 %; therefore, we created a new regression that could be applied to a fully community-dwelling population. This decrease in accuracy could be accounted for by the differing ages and functionality of the participants in each study. The current population was on average 7 years younger and resided independently within the community, while many of the participants from the previous study resided in an assisted-living facility. Of note, the current population scored very high on our clinical assessment of gait/balance, the DGI; mean score was ~ 22 (± 2.4) out of a possible 24 indicating that our population was high functioning. Due to differences within the populations studied currently and the population studied initially, our regression equation evolved and revealed that for community-dwelling older adults, age, BMI, sex, step time, and TOE were the best predictors for the variance of FFMI. These variables predicted FFMI with a high degree of accuracy (~ 83 – 93 %). In theory, careful measurement and tracking of these predictor variables will enable clinicians to predict FFMI and assess sarcopenia, without the use of

expensive body composition devices. Early detection of lowered FFMI (and subsequently sarcopenia) may facilitate implementation of early intervention programs to slow or halt the progression of sarcopenia. The current model has the potential to enable detection *before* an individual is classified as “at risk” of developing further complications due to sarcopenia (according to Fielding et al. in 2011) and in fact was sensitive enough to predict a reduction in fat-free mass before function was severely attenuated, as indicated by the remarkable average gait speed (1.4 ± 0.2 m/s) and high Dynamic Gait Index scores observed in our sample population.

It was interesting to note that grip strength was significantly correlated to FFMI in men but not women and that the opposite held true for age. It should also be noted that each sarcopenic individual had decreased grip strength, but no individuals exhibited a marked decrease in gait speed as defined by the EWGSOP (Cruz-Jentoft et al. 2010). As cadence was negatively correlated to FFMI (and step time was positively correlated), this raised a concern with the current guidelines proposed by the EWGSOP group for the determination of sarcopenia (Cruz-Jentoft et al. 2010). Within our sample population of older adults, women took quicker steps than the men, but in general had a lower quantity of fat-free mass. Men took slower, but longer, steps, which made the average gait speeds identical between sexes. This indicates that more than a simple timed walking task should be performed when attempting to evaluate an individual's functional ability and muscle mass. It should also be noted that each sarcopenic individual in this study was classified as such due to decreased grip strength and *not* decreased gait speed. Gait speed impairments might become an issue in assisted-living facilities or in frail older adults, but this measure is not sensitive enough for early detection of sarcopenia in community-dwelling individuals. In addition to common postural

measures such as ranges and velocities of the center of pressure, the time spent outside a 95 % confidence ellipse area was measured. The frequency of excursions outside the ellipse was not related to FFMI; however, the amount of time spent and displacement outside of this area were positively correlated. This indicates that individuals with more muscle mass were able to have a greater control of their COP outside of their normal sway area. These individuals remained stable while pushing the boundaries of their COP in a controlled manner.

Unfortunately, the nutrition measures used in this study were not strong indicators of fat-free mass quantity. While the literature indicates the importance of protein consumption for muscle development especially in older adults (Kim et al. 2010), there was no correlation between these measures. It should be noted that the average participant consumed 1.10–1.27 g of protein per kilograms of body weight, which is more than the suggested 0.8 g/kg for older adults (Trumbo et al. 2002). Since this sample of older adults consumed on average more protein than the recommended amount for their age group, the muscle deficits observed in this study were likely a result of external factors rather than protein deficiencies. All circumference measures were correlated to FFMI, yet they were poor predictors for the calculated FFMI. Of note, there were no sarcopenic obese participants within our sample population. In larger populations where this may be an issue, circumference measures may prove to be unreliable predictors of FFMI and should therefore be considered cautiously.

While this pilot study was able to recruit 85 reportedly healthy community-dwelling older adults, there were several limitations. The participants were well educated (>57 % of the total population were college/university educated), and as a whole, 75 % either met or exceeded the average physical activity levels outlined by their PASE score as stratified by sex and age (Washburn et al. 1993). Physical and education levels were not inclusion criteria (other than being able to walk for 18 m); however, this reflects some of the socioeconomic and lifestyle attributes associated with one of the retirement areas that made up a large portion of our recruited population. This may limit the predictability of the current equation to all ethnic groups and social classes of older adults. All but two participants returned their 3-day food records. Although food records have been shown to provide more

accurate results than food frequency questionnaires (Prentice et al. 2011), this may have been a limitation, as these records were heavily dependent on accurate descriptions. Multiple lab assistants input these records, which may also have had an effect on the accuracy of their results. There are many steps involved in obtaining nutritional information from a food record which may have compounded error. In the future, this could be avoided by the use of blood samples which give a clear indication of nutrient absorption. This approach is invasive, however, and was not within the scope of the current study. In addition, it would have been ideal to have used a gold standard imaging technique for the body composition measures. This was not a possibility for the current study; however, it would be interesting to validate our proposed model using these alternate tools in the future. Given the studied population, the regression equation presented met all the statistical assumptions, while providing a strong model for predicting fat-free mass index. Lastly, the population used was very high functioning; therefore, future research will involve further testing of this model with older adults residing in an assisted-living facility.

Conclusion

The etiology of sarcopenia is still under debate due to the numerous factors that influence muscle throughout the aging process. The multifaceted nature of this condition makes it necessary to examine a variety of factors to predict the presence of sarcopenia. In this respect, multiple linear regression analysis was ideal for the prediction of fat-free mass index as it included anthropometric, balance, gait, and demographical information. The current model evolved from a previous model proposed by our laboratory group (Krause et al. 2011). While the EWGSOP's definition of sarcopenia was used in the present work, our results suggest that subtle functional changes may not be evident when using this definition in community-dwelling older adults (e.g., reductions in gait speed); we propose that a more diverse and multifaceted working definition is required for clinicians working with this population. For example, we found that different components of gait speed (cadence and step length) were more closely related to FFMI than the overall measurement of gait speed. While the EWGSOP's model is well

respected for the diagnosis of sarcopenia, if early intervention is the ultimate goal, a more sensitive model is required to facilitate the detection of minor changes before major functional deficits occur. The current regression model predicts fat-free mass index with a high degree of accuracy in healthy community-dwelling older adults and should facilitate the accurate prediction of FFMI, and ultimately sarcopenia, by clinicians using simple measurements that are inexpensive and readily available. While TOE is a novel technique that requires a force plate, rapid advancements in technology suggest that the same type of measurement should be available using a simple Wii fit system (an increasingly popular video game that is beginning to be used in research; Clark et al. 2010) in the near future. All other predictors in the model are already available to any clinician. In the future, use of this predictive model to plan intervention strategies to attenuate the progression of sarcopenia may result in a decrease in the risk of falls, even in a high-functioning older adult population.

Acknowledgments We would like to thank our participants from the Village by the Arboretum Retirement Community, the Evergreen Seniors Community Centre, the Guelph Wellington Men's Club, and the Colonel John McCrae Memorial Branch 234 Royal Canadian Legion. We would also like to extend our appreciation to statistician Dr. Michelle Edwards, Dr. Andrea Buchholz from The University of Guelph Body Composition and Metabolism Lab, Dr. Alison Duncan and Dr. Janis-Randall Simpson for use of their BIA unit, and Dr. Amanda Wright and Hillary Tulk from the Human Nutraceutical Research Unit. Lastly, we would like to thank Willy de Wit and Upper Canada Analytical Services for their help with data processing as well as laboratory assistants Sigrid Carino, Nina Falak, Natalie Pond, Cassandra Shipp, Chris Dulhanty, and especially Katherine Harrison for their help with data collection and entry. This work was financially supported by the University of Guelph Research Student Assistantship (to K.B.S.), Ontario Neurotrauma Foundation Summer Internship (to E.I.M.; grant # 2010-PREV-INT-854), and the University of Guelph-Humber Faculty Research Award (to L.A.V.).

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