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ORIGINAL ARTICLE

Physical performance measures as a useful indicator of multiple geriatric syndromes in women aged 75 years and older

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Aim: To identify whether individual physical performance measures or a combination of measures is a better indicator of multiple geriatric syndromes (MGS) defined as the concomitant presence of more than one geriatric syndrome in an individual.

Methods: We carried out cross-sectional analyses on data from 340 community-dwelling women aged 75 years and older (mean 80.0 years). We examined the following geriatric syndromes: urinary incontinence, falls, underweight, depression and functional decline. Trained testers measured usual gait speed (UGS), hand-grip strength and lower extremity performance (LEP) score derived from four LEP measures: tandem stance, chair stand test, alternate step and timed up-and-go (TUG). We categorized UGS to distinguish high- and low-performing participants using the established 1.0 m/s cut-off point. Applying the same population percentile (35.8%), we determined cut-off points for all individual measures and the LEP score.

Results: The UGS, TUG and LEP score had similar discriminating powers for MGS (each with area under receiver–operator curves [AUC] of 0.80), which were more significant than the discriminating powers of other individual measures (AUC = 0.69–0.76) when considered as continuous variables. A slow UGS, especially less than 1.0 m/s, was more strongly associated with MGS (odds ratio [OR] = 7.6, 95% confidence interval [CI] = 3.6–15.9) than the same percentiles for TUG (OR = 3.9, 95% CI = 1.9–7.8) and LEP score (OR = 5.2, 95% CI = 2.5–10.6).

Conclusion: The UGS test alone might be sufficient in detecting MGS in women aged 75 years and older compared with a more comprehensive test battery. **Geriatr Gerontol Int 2013; ••: ••–••.**

Keywords: area under the receiver–operator curve, geriatric syndrome, older adults, physical performance, usual gait speed.

Introduction

Geriatric syndromes are multifactorial health conditions resulting from the accumulated effects of impairments in multiple domains.[1,2] Although the term "syndrome" is generally used to group together multiple symptoms with a single pathogenetic pathway, "geriatric syndrome" primarily refers to one atypical symptom or a complex of symptoms (unified manifestation) with high prevalence in older adults, such as mild cognitive impairment, delirium, dementia, depression, dizziness, senile osteoporosis, falls, sensory loss, malnutrition and weight loss, losses in activities of daily living (ADL), pain, substance abuse, urinary incontinence, and iatrogenic problems.[3] In particular, pressure ulcers, urinary incontinence, falls, functional decline and delirium are common geriatric syndromes based on a review of the literature.[2]

With advancing age, more than one geriatric syndrome can be seen in an individual, because the risk factors of different geriatric syndromes largely overlap.[2,3] Therefore, the most efficient indicator for detecting these multiple symptoms should be used in routine assessments of health status of older adults. Kim *et al.* showed that fear of falling and usual gait speed (UGS)

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were significantly associated with the symptoms of urinary incontinence, falls and functional decline.[4] Indeed, physical performance measures, such as UGS and/or hand-grip strength (HGS), are considered largely representative of a person's general health condition.[5,6]

However, it has not been established which individual physical performance measure is more tightly associated with individual and multiple geriatric syndromes. In addition, a more comprehensive battery might capture individual or multiple geriatric syndromes more efficiently, because a geriatric syndrome represents a unified manifestation resulting from a series of processes or changes suggesting multiple contributors.[2] Cooper *et al.* have mentioned the necessity of investigating whether a derived composite score representing overall lower or upper extremity performance is a stronger predictor of health problems than any of the individual measures.[7] Although previous studies[8–11] have shown that a comprehensive battery of tests tended to be better at predicting or discriminating ADL disability, which is a geriatric syndrome, several studies have also concluded that UGS alone was nearly as good at detecting ADL disability as a comprehensive battery of tests. Thus, the significance of combining several performance measures is still unclear.

In the present study, we examined five geriatric syndromes used in previous studies of older Japanese adults:[4,12] urinary incontinence, falls, underweight, depression and functional decline. Furthermore, the term multiple geriatric syndromes (MGS) was operationally defined as "the concomitant presence of more than one of the geriatric syndromes described above in the same individual." We chose to focus only on older women, because the prevalence of frailty, disability or other functional problems is higher in women than men, although women have a longer life expectancy than men worldwide.[13,14] The purpose of the present study was to identify whether individual physical performance measures or a more comprehensive battery of tests is a better indicator of MGS.

Methods

Participants

A total of 421 community-dwelling, Japanese women aged 75 years and older (mean 80.3 years) participated in the present study. We set the minimum age at 75 years because aging and being older is a common risk factor for geriatric syndrome.[2] The participants were recruited from the towns of Ibaraki ($n = 216$), Chiba ($n = 138$) and Fukushima ($n = 67$), Japan, between 2007 and 2011 as part of a nursing care prevention program or day-care service. Almost all the participants were recruited through local advertisements and flyers. Participants were excluded if they: (i) required a cane or other walking device, or their physical performance could not be measured by a standard method (e.g. they needed physical support from another person; $n = 36$); (ii) could not understand the instructions of performance tests and questionnaires ($n = 11$); or (iii) had data missing from their performance tests and geriatric syndromes ($n = 34$). There were 340 participants remaining, ranging in age from 75 to 96 years (mean 80.0 years old). All participants provided written informed consent. The study protocol was approved by the Ethics Committee of the University of Tsukuba, Japan.

Measurements

Physical performance measures

We compared UGS, HGS, four widely-used lower extremity performance (LEP) measures (tandem stance,[15] chair stand test,[16] alternate step,[17] and timed up-and-go [TUG][18]) and a composite score for LEP that was derived from these four LEP measures. The LEP score was previously developed along with a principal component analysis as a LEP indicator.[11,19]

UGS. Participants were instructed to stand with their feet behind and just touching a starting line marked with tape at 0 m and, on receiving the tester's command, to start walking at their normal pace along a 7-m course. The actual walking speed was measured over 5-m, starting with the first footfall past the 1-m mark and ending with the first footfall after the 6-m mark. Participants carried out two trials with results averaged to the nearest 0.01 m/s. The reliability of UGS was excellent, with an intraclass correlation coefficient (ICC) of 0.98.

HGS. We measured HGS using a hand-held dynamometer (GRIP-D, T.K.K 5401; Takei Scientific Instruments, Tokyo, Japan). Participants stood with their arms hanging naturally at their sides. They were instructed and verbally encouraged to squeeze the hand-grip as hard as possible. Grip size was adjusted to a comfortable level for each participant. Participants carried out two trials with each hand alternately, and the results were average to the nearest 0.1 kg. The reliability of the HGS was excellent, with an ICC of 0.96.

Tandem stance. Participants stood with the heel of one foot directly in front of the toes of the other foot for a maximum of 30 s. The end-point occurred when the participant shifted from the tandem position, lifted or replaced a foot, moved a foot on the floor, or touched any object with their hands to maintain their balance.[15] Participants carried out two trials with the results averaged to the nearest 0.01 s. The reliability of the tandem stance was acceptable with an ICC of 0.79.

Chair stand test. The chair stand test measures the time to move from a sitting to a standing position five times without using the arms. Participants were asked to stand up and sit down on a 46-cm high, straight-backed chair as quickly as possible. The time was measured from the initial sitting position to the final fully erect position at the end of the fifth stand.[16] Participants carried out two trials, and the results were averaged to the nearest 0.01 s. The reliability of the chair stand test was excellent with an ICC of 0.96.

Alternate step. Participants were asked to step with alternate feet onto a raised platform. We measured the time it took to place each foot alternately onto a 19-cm high step eight times.[17] Participants carried out two trials, and the results were averaged to the nearest 0.01 s. The alternate step had an excellent reliability with an ICC of 0.96.

TUG. Participants were asked to rise from a 46-cm high chair, walk forward 3 m as quickly as possible, turn 180 degrees and walk around a cone, walk back to the chair, and sit down.[18] Participants carried out two timed trials with the results averaged to the nearest 0.01 s. The reliability of the TUG was excellent with an ICC of 0.99.

LEP score. We calculated the LEP score using tandem stance, chair stand test, alternate step and TUG. The LEP score was developed to identify individuals at a high risk of frailty based on Japan's long-term care insurance system.[20] We selected these measures for their significant relevant factors for high risk of frailty based on Japan's long-term care insurance system[20] after examining, with logistic regression analysis, 12 performance-based measures.[19] The LEP score is distributed with a mean of 0 and a standard deviation of 1.0, and can be calculated with the following equation: LEP score $= 0.031X_1 - 0.106X_2 - 0.192X_3 - 0.096X_4 + 1.672$, where X_1 = tandem stance (s), X_2 = chair stand test (s), X_3 = alternate step (s) and X_4 = TUG (s). This equation is weighted using the coefficients of principal component scores obtained from a principal component analysis. This analysis provides the first principal component, which accounts for the largest variance among the extracted components. The first principal component is a useful statistical tool combining all explanatory variables into a single expression.[21] Because the first principal component represents a linear combination of tandem stance, chair stand test, alternate step and TUG, this component can be used as an overall index of LEP measures. This method has been described in more detail elsewhere.[21–25]

Geriatric syndromes

Face-to-face interviews enabled us to determine which participants experienced urinary incontinence, falls, presence of depression and functional decline. To minimize recall bias, skilled interviewers, who had been trained and certified in measurement techniques, carried out the interviews. To identify urinary incontinence, we looked at aspect of bladder emptying using the Barthel Index.[26] Interviewers asked participants, "Have you experienced urine leakage during the past month?" The participants answering "yes" were defined as having urinary incontinence. The interviewers asked the question "Have you fallen in the past year?" for information on falls. A fall was defined as an unexpected event in which the participant comes to rest on the ground, floor or other lower level.[27,28] Coming to rest against furniture or a wall was not counted as a fall. Participants reporting one or more falls were categorized as fallers. Depression was assessed using a two-part question from the Center for Epidemiological Studies-Depression scale:[29] "How often in the last week did you feel this way? (a) I felt that everything I did was an effort. (b) I could not get going." Participants who said "more than 3 days" to either part (a) or part (b) were categorized as depressed.[30] We used the Tokyo Metropolitan Institute of Gerontology (TMIG) index of competence[31] to assess functional decline. The response to each item in this multidimensional, 13-item index of competence is either "yes" (able to perform) for 1 point or "no" (unable to perform) for 0 points. A total score less than 11 defined the participants as having functional decline.[32,33] We considered a participant as underweight if she had a body mass index (BMI; bodyweight divided by height squared [kg/m^2]) less than 18.5 kg/m^2. We classified participants having two or more geriatric syndromes as suffering from MGS.

Potential confounders

There were several potential confounders in our analyses: age; clinical conditions (history of stroke, hypertension, diabetes mellitus, heart disease, respiratory disease, osteoporosis and dyslipidemia); and joint pain (presence of low-back pain, or knee pain). All of these were determined through face-to-face interview. Although we investigated frequency of weekly outings, along with smoking and alcohol habits, we did not include them as potential confounders in our analyses, because we did not receive this information from all participants.

Statistical analyses

We used descriptive statistics to characterize the study participants. To compare the power of the six physical performance measures individually, and the LEP score for detecting the presence of each geriatric syndrome and MGS, we carried out receiver–operating characteristic (ROC) analyses. Areas under the ROC curves (AUC), and 95% confidence intervals (CI) of the six physical performance measures and LEP score were compared using the DeLong method[34] implemented in the statistical software Analyse-It for Microsoft Excel (Analyse-it Software, Leeds, UK). Independent variables used in the present study included the six physical performance measures and the LEP score, whereas the presence of each geriatric syndrome and MGS were dependent variables. An AUC between 0.7 and 0.8 was considered acceptable discrimination, between 0.8 and 0.9 was considered excellent discrimination, and greater than 0.9 was considered outstanding discrimination.[35]

To evaluate which performance measures, when diminished, had the strongest association with each geriatric syndrome and MGS, we carried out multiple logistic regression analyses. Cesari *et al.* showed that the prognostic value of UGS for identifying people at high risk of health-related outcomes was at a cut-off value of 1.0 m/s.[36] In our analyses, we used the 1.0 m/s cut-off value to dichotomize UGS into high- and low-performance groups. Other individual performance measures and the LEP score were dichotomized using the same population percentile (35.8%) as the UGS 1.0 m/s cut-off value. We determined these percentiles based on the distribution of the present study sample population. By maintaining the same threshold to identify individuals at a low-performance level, we determined equal distributions of the performance measures of interest, consequently allowing fair comparisons.[37] We adjusted for potential confounders and calculated the odds ratios (OR) and 95% CI for the presence of each geriatric syndrome and MGS according to our two categories: the high-performance category, which we considered a reference group; and the low-performance category.

We used an alpha level of 0.05 to determine statistical significance and performed all statistical analyses using SPSS statistics Version 19.0 (SPSS Inc., Chicago, IL, USA).

Results

Table 1 summarizes descriptive details of the study participants. There were 29 (8.5%) participants who had experienced urinary incontinence, 92 (27.1%) who had experienced falls, 22 (6.5%) who were underweight, 34 (10.0%) with depression, and 117 (34.4%) with functional decline. There were a total of 69 (20.3%) participants with MGS in our study. Of these 69 participants with MGS, the greatest number (*n* = 25) had concomitant presence of falls and functional decline.

Table 2 shows the AUC and 95% CI of each performance measure, and the LEP score for identifying individual geriatric syndromes and MGS. The ROC curves of tandem stance for urinary incontinence and for all performance measures except HGS for underweight were not significantly different from the diagonal line (AUC = 0.5), which indicates zero discriminating ability of the tests. All other ROC curves were significantly different from the diagonal line.

For each geriatric syndrome, the greatest AUC value was generally seen with UGS, TUG, and LEP score. However, for the underweight, only HGS had significant and acceptable discriminating power (AUC = 0.71), and its AUC was significantly greater than AUC of other performance measures (AUC = 0.53-0.60). For MGS, the UGS, TUG, and LEP score had excellent discriminating power (AUC = 0.80) with no significant difference between their AUC, and these AUC were significantly greater than the AUC of other individual performance measures (AUC = 0.69–0.76).

Table 3 presents OR and 95% CI for the presence of each geriatric syndrome and MGS according to participants' individual performance measures and LEP scores. For our participants, the 1.0 m/s cut-off value for UGS corresponded to the 35.8th percentiles. We used these same percentiles to identify cut-off values for HGS (low-performance group <17.3 kg), tandem stance (low-performance group <23.30 s), chair stand test (low-performance group >9.70 s), alternate step (low-performance group > 5.80 s), TUG (low-performance group >8.90 s) and LEP score (low-performance group <–0.66).

A slower UGS and weaker HGS were significantly associated with all geriatric syndromes except underweight and urinary incontinence, respectively. As with the ROC analyses, the OR and CI indicated that only a weaker HGS was significantly associated with being underweight (OR 3.4, 95% CI 1.2–9.4), whereas the associations between other geriatric syndromes and HGS were generally weaker than their associations with other significantly-related performance measures. Although a lower LEP score had the largest OR for falls (OR 2.4, 95% CI 1.3–4.3), depression (OR 2.9, 95% CI 1.2–6.8) and functional decline (OR 4.8, 95% CI 2.6–8.7), among the individual performance measures, only a slower UGS had similar OR for all of the geriatric syndromes. The chair stand test and TUG were significantly associated with three geriatric syndromes. A slower chair stand test was associated with urinary incontinence (OR 2.7, 95% CI 1.1–6.7), falls (OR 2.0, 95% CI 1.1–3.5) and functional decline (OR 4.1, 95% CI 2.4–7.3). A slower TUG was associated with urinary incontinence (OR 2.8, 95% CI 1.1–7.3), depression (OR 2.7, 95% CI 1.1–6.5) and functional decline (OR 3.8, 95% CI 2.1–6.8). These two tests had similar OR for urinary incontinence and functional decline; however,

Table 1 Characteristics of the study participants

Characteristics	Mean ± standard deviation or n (%)
Age, years ($n = 340$)	80.0 ± 4.6
Body mass index, kg/m^2 ($n = 340$)	23.5 ± 3.6
Frequency of weekly outings, days/week ($n = 323$)	5.5 ± 2.1
Smoking habit ($n = 278$)	
Never	265 (95.3)
Former	6 (2.2)
Current	7 (2.5)
Alcohol habit ($n = 278$)	
Abstain	242 (87.1)
Moderate (1–4 days/week)	27 (9.7)
Heavy (almost every day)	9 (3.2)
Conditions, n (%)	
Stroke ($n = 337$)	19 (5.6)
Hypertension ($n = 338$)	168 (49.7)
Diabetes mellitus ($n = 338$)	28 (8.3)
Heart disease ($n = 337$)	50 (14.8)
Respiratory disease ($n = 338$)	8 (2.4)
Osteoporosis ($n = 337$)	51 (15.1)
Dyslipidemia ($n = 337$)	37 (11.0)
Low-back pain ($n = 335$)	129 (38.5)
Knee pain ($n = 335$)	129 (38.5)
Performance measures ($n = 340$)	
Usual gait speed (m/s)	1.09 ± 0.30
Hand-grip strength (kg)	19.0 ± 4.6
Lower extremity performance score	−0.67 ± 1.25
Tandem stance (s)	23.2 ± 9.7
Chair stand test (s)	9.9 ± 3.9
Alternate step (s)	5.9 ± 2.1
Timed up-and-go (s)	9.3 ± 4.2
Geriatric syndromes ($n = 340$)	
Urinary incontinence, n (%)	29 (8.5)
Falls, n (%)	92 (27.1)
Underweight, n (%)	22 (6.5)
Depression, n (%)	34 (10.0)
Functional decline, n (%)	117 (34.4)
Multiple geriatric syndromes (having 2 or more geriatric syndromes)	69 (20.3)
No. geriatric syndromes ($n = 340$)	
0, n (%)	141 (41.5)
1, n (%)	130 (38.2)
2, n (%)	46 (13.5)
3, n (%)	21 (6.2)
4, n (%)	1 (0.3)
5, n (%)	1 (0.3)
Combination patterns of multiple geriatric syndromes ($n = 69$)	
Urinary incontinence + falls	1 (1.4)
Urinary incontinence + functional decline	4 (5.8)
Falls + underweight	3 (4.3)
Falls + depression	1 (1.4)
Falls + functional decline	25 (36.2)
Underweight + functional decline	5 (7.2)
Depression + functional decline	7 (10.1)
Urinary incontinence + falls + depression	1 (1.4)
Urinary incontinence + falls + functional decline	4 (5.8)
Urinary incontinence + underweight + functional decline	2 (2.9)
Urinary incontinence + depression + functional decline	3 (4.3)
Falls + underweight + depression	1 (1.4)
Falls + underweight + functional decline	2 (2.9)
Falls + depression + functional decline	7 (10.1)
Underweight + depression + functional decline	1 (1.4)
Urinary incontinence + falls + depression + functional decline	1 (1.4)
Urinary incontinence + falls + underweight + depression + functional decline	1 (1.4)

$n = 340$. Lower extremity performance score = 0.031 × tandem stance − 0.106 × chair stand test − 0.192 × alternate step − 0.096 × timed up-and-go + 1.672.

Table 2 Areas under the receiver operating characteristic curves, and 95% confidence intervals of physical performance for individual and multiple geriatric syndromes

Physical performance measures	Individual geriatric syndromes					Multiple geriatric syndromes
	Urinary incontinence	Falls	Underweight	Depression	Functional decline	Having 2 or more geriatric syndromes
	AUC (95% confidence interval)					
Usual gait speed	0.69 (0.58–0.81)	0.63 (0.56–0.69)	0.56 (0.43–0.70)[b]	0.72 (0.62–0.81)	0.78 (0.73–0.83)[b]	0.80 (0.74–0.86)[b]
Hand-grip strength	0.64 (0.53–0.75)	0.59 (0.53–0.66)[d]	0.71 (0.61–0.81)[acd]	0.67 (0.57–0.77)	0.70 (0.64–0.76)[acd]	0.72 (0.65–0.80)[acd]
Tandem stance	0.58 (0.48–0.69)[acd]	0.62 (0.55–0.69)	0.60 (0.48–0.72)[b]	0.66 (0.56–0.77)	0.67 (0.61–0.73)[acd]	0.69 (0.62–0.76)[acd]
Chair stand test	0.68 (0.57–0.79)	0.63 (0.56–0.70)	0.54 (0.42–0.67)[b]	0.64 (0.54–0.75)[ad]	0.76 (0.70–0.81)[b]	0.76 (0.69–0.82)[acd]
Alternate step	0.67 (0.56–0.79)	0.62 (0.56–0.69)	0.55 (0.44–0.66)[b]	0.64 (0.53–0.76)[ad]	0.74 (0.68–0.79)[acd]	0.76 (0.69–0.82)[acd]
Timed up-and-go	0.72 (0.61–0.83)	0.64 (0.57–0.71)	0.53 (0.38–0.68)[b]	0.71 (0.61–0.81)	0.79 (0.74–0.84)[b]	0.80 (0.74–0.86)[b]
Lower extremity performance score	0.70 (0.59–0.81)	0.66 (0.59–0.72)[b]	0.56 (0.44–0.68)[b]	0.69 (0.58–0.80)	0.79 (0.74–0.85)[b]	0.80 (0.75–0.86)[b]

Areas under the receiver–operating characteristic curves (AUC) range 0.5–1.0. Degree of discrimination: 0.7–0.8 acceptable, 0.8–0.9 excellent, 0.9–1.0 outstanding.[35] Underline: the ability to discriminate geriatric syndrome significantly differed from zero. [a]$P < 0.05$ versus usual gait speed. [b]$P < 0.05$ versus hand-grip strength. [c]$P < 0.05$ versus timed up-and-go. [d]$P < 0.05$ versus lower extremity performance score. Lower extremity performance score = 0.031 × tandem stance – 0.106 × 5 chair sit-to-stands – 0.192 × alternate step – 0.096 × timed up-and-go + 1.672. Independent variables: usual gait speed, hand-grip strength, tandem stance, chair stand test, alternate step, timed up-and-go, and lower extremity performance score. Dependent variable: urinary incontinence, falls, underweight, depression, functional decline and multiple geriatric syndromes.

Table 3 Adjusted odds ratios and 95% confidence intervals for individual and multiple geriatric syndromes according to physical performance

Physical performance measures (cut-off value: 35.8 percentile)	Individual geriatric syndromes										Multiple geriatric syndromes	
	Urinary incontinence		Falls		Underweight		Depression		Functional decline		Having 2 or more geriatric syndromes	
	Case/ participants (%)	Adjusted odds ratio (95% CI)	Case/ participants (%)	Adjusted odds ratio (95% CI)	Case/ participants (%)	Adjusted odds ratio (95% CI)	Case/ Participants (%)	Adjusted odds ratio (95% CI)	Case/ participants (%)	Adjusted odds ratio (95% CI)	Case/ participants (%)	Adjusted odds ratio (95% CI)
Usual gait speed												
≥1.0 m/s (high-performance)	10/212 (4.7)	1 (reference)	41/212 (19.3)	1 (reference)	12/212 (5.7)	1 (reference)	12/212 (5.7)	1 (reference)	42/212 (19.8)	1 (reference)	16/212 (7.5)	1 (reference)
<1.0 m/s (low-performance)	19/118 (16.1)	3.6 (1.4–9.2)**	42/118 (35.6)	1.9 (1.1–3.4)*	10/118 (8.5)	2.9 (0.9–8.8)	22/118 (18.6)	2.8 (1.2–6.6)*	71/118 (60.2)	4.4 (2.4–8.0)***	49/118 (41.5)	7.6 (3.6–15.9)***
Hand-grip strength												
≥17.3 kg (high-performance)	15/212 (7.1)	1 (reference)	42/212 (19.8)	1 (reference)	9/212 (4.2)	1 (reference)	12/212 (5.7)	1 (reference)	48/212 (22.6)	1 (reference)	22/212 (10.4)	1 (reference)
<17.3 kg (low-performance)	14/118 (11.9)	0.9 (0.4–2.2)	41/118 (34.7)	1.8 (1.0–3.2)*	13/118 (11.0)	3.4 (1.2–9.4)	22/118 (18.6)	2.8 (1.2–6.3)*	65/118 (55.1)	2.5 (1.4–4.3)**	43/118 (36.4)	2.7 (1.4–5.2)**
Tandem stance												
≥23.30 s (high-performance)	14/212 (6.6)	1 (reference)	42/212 (19.8)	1 (reference)	11/212 (5.2)	1 (reference)	15/212 (7.1)	1 (reference)	55/212 (25.9)	1 (reference)	27/212 (12.7)	1 (reference)
<23.30 s (low-performance)	12/118 (12.7)	1.7 (0.7–3.9)	41/118 (34.7)	1.7 (1.0–3.0)*	11/118 (9.3)	2.3 (0.9–6.2)	19/118 (16.1)	2.0 (0.9–4.3)	58/118 (49.2)	1.8 (1.1–3.2)*	38/118 (32.2)	2.3 (1.2–4.3)*
Chair stand test												
≤9.70 s (high-performance)	11/212 (5.2)	1 (reference)	41/212 (19.3)	1 (reference)	14/212 (6.6)	1 (reference)	15/212 (7.1)	1 (reference)	43/212 (20.3)	1 (reference)	24/212 (11.3)	1 (reference)
>9.70 s (low-performance)	18/118 (15.3)	2.7 (1.1–6.7)*	42/118 (35.6)	2.0 (1.1–3.5)*	8/118 (6.8)	0.9 (0.3–2.6)	19/118 (16.1)	1.7 (0.8–3.8)	70/118 (59.3)	4.1 (2.4–7.3)***	41/118 (34.7)	2.9 (1.5–5.6)**
Alternate step												
≤5.80 s (high-performance)	12/212 (5.7)	1 (reference)	42/212 (19.8)	1 (reference)	15/212 (7.1)	1 (reference)	16/212 (7.5)	1 (reference)	44/212 (20.8)	1 (reference)	21/212 (9.9)	1 (reference)
>5.80 s (low-performance)	17/118 (14.4)	2.2 (0.9–5.7)	41/118 (34.7)	1.7 (0.9–3.0)	7/118 (5.9)	0.8 (0.2–2.5)	18/118 (15.3)	1.4 (0.6–3.3)	69/118 (58.5)	3.3 (1.9–5.8)***	44/118 (37.3)	3.4 (1.7–6.7)***
Timed up-and-go												
≤8.90 s (high-performance)	10/212 (4.7)	1 (reference)	45/212 (21.2)	1 (reference)	12/212 (5.7)	1 (reference)	12/212 (5.7)	1 (reference)	41/212 (19.3)	1 (reference)	19/212 (9.0)	1 (reference)
>8.90 s (low-performance)	19/118 (16.1)	2.8 (1.1–7.3)*	38/118 (32.2)	1.4 (0.8–2.5)	10/118 (8.5)	2.0 (0.7–6.2)	22/118 (18.6)	2.7 (1.1–6.5)*	72/118 (61.0)	3.8 (2.1–6.8)***	46/118 (39.0)	3.9 (1.9–7.8)***
Lower extremity performance score												
≥−0.66 (high-performance)	12/212 (5.7)	1 (reference)	38/212 (17.9)	1 (reference)	13/212 (6.1)	1 (reference)	12/212 (5.7)	1 (reference)	40/212 (18.9)	1 (reference)	18/212 (8.5)	1 (reference)
<−0.66 (low-performance)	17/118 (14.4)	2.2 (0.9–5.7)	45/118 (38.1)	2.4 (1.3–4.3)**	9/118 (7.6)	1.5 (0.5–4.5)	22/118 (18.6)	2.9 (1.2–6.8)*	73/118 (61.9)	4.8 (2.6–8.7)***	47/118 (39.8)	5.2 (2.5–10.6)***

$n = 330$. Odds ratio: adjusted for age, stroke, hypertension, diabetes mellitus, heart disease, respiratory disease, osteoporosis, dyslipidemia, low back pain and knee pain. Underline: significant results.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. Lower extremity performance score = 0.031 × tandem stance − 0.106 × chair stand test − 0.192 × alternate step − 0.096 × timed up-and-go + 1.672. Independent variables: usual gait speed, hand-grip strength, tandem stance, chair stand test, alternate step, timed up-and-go, and lower extremity performance score. Dependent variables: urinary incontinence, falls, underweight, depression, functional decline and multiple geriatric syndromes.

they were lower than the OR of UGS. Although a poor result for the tandem stance was significantly associated with falls (OR 1.7, 95% CI 1.0–3.0) and functional decline (OR 1.8, 95% CI 1.1–3.2), these were the weakest associations among all the significantly-related performance measures. A slower alternate step was significantly associated only with functional decline (OR 3.3, 95% CI 1.9–5.8).

Finally, there were significant associations between MGS and poor scores on any of the individual performance tests or a lower LEP score. In particular, a slower UGS had the greatest OR (7.6, 95% CI 3.6–15.9) among all performance measures, even when compared with a low LEP score (OR 5.2, 95% CI 2.5–10.6).

Discussion

We determined that the greatest discriminating power for each geriatric syndrome was generally seen with UGS, TUG and the LEP score when considered as continuous variables, and the result was consistent for MGS. The discriminating power of these three measures for MGS (each with an AUC of 0.80) was significantly greater than that of other individual performance measures (AUC = 0.69–0.76), and we regarded this greater than 5% difference as substantial after reviewing several previous studies.[8,38–40] Furthermore, although UGS, TUG and LEP score had the same discriminating power for MGS, a slower UGS and lower LEP score generally had the greatest adjusted OR for each geriatric syndrome. In particular, a UGS less than 1.0 m/s was more tightly associated with MGS than was a lower LEP score. These results show that a decreased UGS is an important sign of MGS among women aged 75 years and older.

Similar to UGS, HGS is considered largely representative of a person's general health condition,[5] and also as a standardized measure of muscle strength or nutritional status.[41] However, women originally have less skeletal muscle than men, and these sex differences are more pronounced in the upper body.[42] In addition, because women had slower rates of decline in HGS than men,[43] decreased HGS might be more difficult to actualize as a sign of MGS in women than men.

Our present findings are consistent with previous studies showing that UGS alone is nearly as good as more comprehensive batteries (e.g. short physical performance battery)[16] for detecting a decline of functional status.[8,10,11] These results would not change, even if we include UGS in the LEP score, because TUG predicted adverse-health outcomes as well as UGS, and combining the two measures did not add extra predictive ability.[44]

A noteworthy finding of the present study is that a slower UGS indicated MGS in older women more strongly than did a lower LEP score. Montero-Odasso *et al.* proposed an interesting hypothesis that a decreased UGS might reflect a complex interaction among several impairments.[45] Walking is a task coordinating and integrating multidimensional factors: central nervous system, perceptual system, peripheral nervous system, muscles, bone/joints and energy production/delivery.[46] This is different from HGS, which requires only a regional task (e.g. grasp). Therefore, good overall functioning is required to maintain an adequate UGS, and the burden of potential impairments might actualize as the inability to maintain an adequate UGS.

With this in mind, we consider UGS to be an indicator of the extent of cumulative age-related body changes or disease burdens. Studenski *et al.* carried out a pooled analysis of nine cohort studies collected between 1986 and 2000 using data from 34 485 older adults aged 65 years or older with baseline UGS data.[47] They showed that a UGS of 1.0 m/s or faster consistently showed a longer survival time than what was expected by age and sex alone. Cesari *et al.* also showed that people with a UGS faster than 1.0 m/s have longer survival times and a lower risk of adverse-health outcomes, such as (severe) mobility limitation and hospitalization.[36,37] Furthermore, Takahashi *et al.* investigated walking speed at 130 crosswalks, and reported that at least 1.0 m/s was required to safely cross the street in Japan.[48] These findings show the importance of an individual maintaining her UGS at least to a standard level (i.e. 1.0 m/s).

We believe that there are two approaches to physical performance measures: first as an indicator of a person's overall well-being (i.e. epidemiological indicator); second as a specific indicator of localized function (e.g. upper extremity muscle strength, balance or flexibility) to assess effects of intervention.

In the former case, although we hypothesized that combining several measures would be more useful than UGS alone, we found few advantages to combining performance measures as shown by the results of the present study. Therefore, we believe UGS should be the performance test of choice for assessing an older woman's overall health status, and it should be monitored routinely like blood pressure or pain.

In contrast, as a specific indicator of localized function, UGS alone is insufficient and the concurrent use of other physical performance measures or a more comprehensive battery of tests is desirable; an intervention might have a differential impact on different body parts and should be monitored with appropriate regional measures or a battery of tests. When evaluating the effects of intervention, the concurrent use of other physical performance measures or a more comprehensive battery of tests might provide more useful information than UGS alone.

There were several limitations to the present study. First, population studies of older adults can sometimes be affected by a selection bias, because relatively healthy people tend to participate. Second, because our participants were all aged 75 years or older, the present results might not be applicable to other age groups. In fact, the UGS was more sensitive in predicting the onset of functional dependence for people aged 75 years and older, whereas maximum gait speed was more sensitive for people aged 65–74 years.[49] UGS might not physically stress the younger age group (65–74 years) sufficiently. Third, we examined just five geriatric syndromes, those used in previous studies of older Japanese adults.[4,12] If we increased the number of geriatric syndromes in the present study, participants with MGS would also increase. In addition, we assessed urinary incontinence using self-reported data obtained through a simple question; however, not all types of urinary incontinence are related to physical function, and we could not confirm participants' urinary incontinence type (i.e. stress incontinence, urge incontinence, overflow incontinence or functional incontinence). Likewise, depression among older adults might be complex because of a wide range of severity and comorbid symptoms, such as cerebrovascular disorders, anxiety disorders and substance use disorders.[50] Thus, several different factors that we could not investigate in the present study, along with physical performance, might also influence participants' depression. Fourth, the present study was a cross-sectional study, which cannot discern cause–effect. Finally, although we were able to adjust our analyses for health information, there could be unmeasured confounders for which we could not adjust.

In conclusion, the UGS and LEP score could both discriminate MGS with a similar power; they certainly did this better than HGS, when considered as continuous variables. However, using a slow UGS, especially less than 1.0 m/s, was more tightly associated with MGS than was a lower LEP score. The UGS alone might be sufficient in detecting the MGS compared with a more comprehensive test battery. We recommend it as a routine assessment measure of health status in women aged 75 years and older.

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Disclosure statement

None to declare.

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Validity of the bioelectrical impedance method for assessing body composition in non-frail and pre-frail older adults

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Objective: There are few studies testing the accuracy of bioelectrical impedance analysis (BIA) as a method for detecting body composition in older adults, including the pre-frail. This study compares body composition measured with BIA and dual X-ray absorptiometry (DXA) in non-frail and pre-frail older adults.
Methods: We recruited 166 participants including 60 older adults (75.0 ± 5.7 years, 65-88 years, 41 women and 19 men) classified, according to Fried's definition, as non-frail (34 older adults, 74.5 ± 6.6 years) and pre-frail (26 older adults, 75.5 ± 4.5 years). Fat mass (FM) and fat-free mass (FFM) were estimated by DXA (DPX-LIQ, GE Healthcare) and BIA (MC-190, Tanita, Japan). We also compared this data with 106 healthy adults (39.4 ± 12.4 years, 20-64 years, 55 men and 51 women).
Results: There were no differences between BIA and DXA results for FM in the non-frail and FFM in the pre-frail. However, significant differences were observed for FM in the pre-frail and FFM in the non-frail (FMBIA:18.4±5.6, FMDXA:16.9±5.0; FFMBIA:40.9±7.3, FFMDXA:40.0±6.7, $P < 0.05$, respectively). The DXA and BIA-derived body composition parameters correlated significantly with each other in the non-frail and pre-frail (FM: $r = 0.94$, 0.97 and FFM: $r = 0.98$, 0.97, all $P < 0.01$, respectively). Bland-Altman plots demonstrated that there was a tendency towards an increasing overestimation of FM by BIA with increasing FM ($r = -0.39$, $P = 0.05$). In younger group, excellent correlation was observed between BIA and DXA (FM: $r = 0.93$, FFM $= 0.98$, $P < 0.01$, respectively). FMBIA tended to be overestimated with increasing FM ($r = -0.27$, $P = 0.05$) in Bland-Altman analysis.
Conclusion: As compared to the DXA method, we found the BIA accurately assessed body composition in non-frail and pre-frail older adults, although FM had proportional bias. The accuracy of BIA did not differ between the younger and the elderly population.

Keywords: Non-frail; Pre-frail; Older adults; BIA; DXA

Introduction

Frailty in older adults has become a growing concern. In general, frailty can be defined as a geriatric syndrome that places older adults at a high risk of adverse health outcomes, including falls, institutionalization, hospitalization, and mortality [1].

Assessing body composition in older adults has therefore become increasingly important. A loss of muscle mass and an increase in fat mass are consistent changes observed with advancing age. These changes in body composition have been linked to a greater risk of morbidity, disability, and mortality [2]. Notably, sarcopenic-obesity, a condition in which older adults experience both low muscle mass and high fat mass, has been of great interest [3]. Several studies have shown an association between sarcopenic-obesity and a higher risk of functional impairment and physical disability [3-5].

Frailty and sarcopenia are related and overlapping. While some older adults with sarcopenia are frail, most frail older adults are also sarcopenic [6,7].

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Hubbard et al. [8] revealed that older adults underweight and overweight assessed by BMI are at risk of frailty. Thus, both sarcopenia and obesity ought to be regarded as potential signs of frailty.

Several techniques are available for estimating body composition. Dual X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) are two commonly used methods for assessing body composition. DXA, which has been compared to other technologies such as hydrostatic weighing, MRI (magnetic resonance imaging system) and CT (computed tomography) [9-12], is one of the most accurate approaches for measuring body composition. It has been used as a reference method since it can precisely detect whole body composition and has been validated against multi-component models [13]. DXA is limited, however, because subjects receive exposure to low-dose radiation, the equipment is expensive.

Alternatively, BIA can be used to easily estimate body composition. A number of studies have shown BIA to be safe, simple to perform, valid, and reliable [14-16]. BIA also offers advantages in its portability and relatively inexpensive price compared to the other methods. Thus, this BIA is suitable for older adults, especially for less mobile or frail adults in clinical settings.

BIA has been recognized as a reliable method for evaluating body composition in younger people [17,18], but the accuracy of measuring body composition with the BIA method in older people is controversial [19], owing to changes in fat distribution and hydration of older adults [20]. Kim et al. [21] reported that multi-frequency BIA can accurately estimate body composition using DXA as a reference method in 69 healthy older Japanese adults, aged 60-88 years. In a similar way, Haapala et al. [22] showed that BIA had a good agreement with DXA in the assessment of fat free mass and fat mass in 93 Finnish women, aged 62-72 years. Although these studies have examined the validity of BIA compared to DXA as a reference in older adults, no previous study has tested its validity in pre-frail older adults.

The purpose of this study was to examine whether the BIA could accurately estimate body composition in older adults, especially pre-frail older adults, using DXA as a reference method.

Methods

Participants

A total of 60 Japanese men and women aged 65-88 years were recruited through poster advertisements and flyers in senior centers and leisure centers from the town of Chiba in 2008. The participants had to meet the following inclusion criteria for the study: (1) aged 65 years or older, (2) able to walk with or without a walking aid, (3) able to understand the instructions and perform the physical tests, (4) absence of terminal disease or progressive deterioration of health, and (5) absence of history of any neurological disease (eg, stroke or Parkinson's disease) with residual impairment. In addition, we recruited 106 healthy adults, age 20-64 years (39.4 ± 12.4 years, 55 men and 51 women) to compare with the older adults' data in our study. All of the participants read and signed the informed, written consent that was approved by the institutional review board for testing. This study was conducted in accordance with the guidelines proposed in the Declaration of Helsinki, and the study protocol was reviewed and approved by the Ethics Committee of University of Tsukuba, Japan.

Classification by Fried's definition

Fried et al. defined frailty through the evaluation of five different components [1]: 1) Weight loss, identified as unintentional weight loss in the past year; 2) Exhaustion, measured using two statements by the Center for Epidemiologic Studies-Depression scale (CES-D) [23]; 3) Low physical activity, assessed with a self-reported questionnaire; 4) Slowed walking speed, measured by a 4.5 m walking test; and 5) Decreased grip strength, assessed by a hand-held dynamometer. A person was considered as pre-frail if 1 or 2 of the above criteria were present. If no criteria were present, the person was considered as non-frail.

Anthropometric variables. We measured body height to the nearest 0.1 cm using a wall-mounted stadiometer (YAGAMI, YG-200). Body weight was assessed to the nearest 0.01 kg using DXA equipment (DPX-LIQ, GE Healthcare). We then calculated body mass index (BMI, kg/m^2) as body weight in kilograms divided by squared height in meters.

Body composition. We measured body composition by BIA using a Body Composition Analyzer MC-190 (Tanita Corp., Tokyo, Japan). For the BIA procedure, we required the participants to prepare as follows: (1) fast and no alcohol for 8 h before measurement; (2) void bladder before measurement; (3) no exercise for 8 h before measurement; and (4) clean their skin with 70 % alcohol (Gibson et al., 2004). We instructed the participant to stand on the footplate electrodes on the analyzer holding the handgrip electrodes with both hands. This device applies multiple-frequency (5 kHz, 50 kHz, 250 kHz, and 500 kHz) BIA technology and has 8 tactile electrodes. We measured the participant's whole body impedance using an ipsilateral foot-hand electrical pathway. This analyzer automatically calculates percentage of total body fat (%FM), BMI, fat mass (FM), fat-free mass (FFM) and total body water using specialized software (Tanita Corp., Tokyo, Japan).

As a reference method, we also measured whole body composition with DXA (DPX-LIQ, GE Healthcare). The densitometer calculated soft tissue mass, including fat and lean tissue masses, from the ratio of mass attenuation coefficients (R value) at 40–50 keV and 80–100 keV. We analyzed body fat, lean tissue mass and bone mineral content according to the manufacturer's instructions. Fat-free mass was defined as lean tissue mass plus bone mineral content. Participants were required to remove all metal items and to wear only hospital gowns for accurate body composition measurements. A trained professional performed the scans with participants in the supine position. To minimize technical error, the same examiner operated the densitometer and positioned the participant.

Statistical analysis

Values are expressed as means ± standard deviation (SD). We applied a paired Student's t-test to compare differences in body composition measurements between the two methods. We examined differences between the groups (younger and elderly participants or pre-frail and non-frail people) by independent sample t-tests. Pearson s correlation coefficients were used to analyze relationships between results from DXA and BIA. Using Bland-Altman plots, [24] we assessed the potential bias between the BIA and DXA methods. This analysis allows for the calculation of bias (estimated by the mean differences), the 95% confidence interval for the bias, and the limits of agreement (2 SDs of the difference) [24]. Multiple regression analyses were conducted to determine correlations for the bias between DXA and BIA. A P-value less than 0.05 was regarded as statistically significant. We used the Statistical Package for the Social Sciences (SPSS) Version 12.0 J for Windows for the statistical analysis.

Results

Table 1 shows the anthropometric variables of the elderly group (non-frail and pre-frail) and younger group. Significant differences were observed between elderly group and younger group in age and height. We also find significant differences between men and women in height, weight, and BMI.

Table 2 shows the body composition variables of the elderly group (non-frail and pre-frail) and younger group. Significant differences were observed between elderly group and younger group in FMBIA, %, FMDXA, %, FMBIA, kg, and FFMBIA, kg. In elderly group, there were significant differences between the BIA and DXA methods in %FM and FM for the total group and pre-frail group, and in FFM for the total group and non-frail group. By contrast, there were no significant differences between BIA and DXA results in the non-frail and pre-frail groups. With regard to younger group, there were significant differences between the BIA and DXA methods in %FM, FM, and FFM for the total group, as well as in subgroups of men and women. We could find significant differences between men and women in FMBIA, %, FMDXA, %, FFMBIA, kg, and FFMDXA, kg.

Table 3 summarizes the simple regression analyses for FFM and FM using DXA as the reference method. Significant correlations between the two methods for measuring FM and FFM were r = 0.95 and r = 0.97 for

Table 1. Anthropometric variables of the participants.

	Total elderly group (n = 60)	Non-frail (n = 34)	Pre-frail (n = 26)	Total younger group (n = 106)	Men (n = 55)	Women (n = 51)
Age, years	75.0 ± 5.7	74.6 ± 6.6	75.5 ± 4.5	39.4 ± 12.4*	41.5 ± 13.0	37.2 ± 11.5
Height, cm	152.4 ± 7.5	153.9 ± 6.8	150.5 ± 6.8	163.4 ± 7.9*	168.7 ± 6.0	157.7 ± 5.5†
Weight, kg	54.5 ± 9.1	55.7 ± 7.3	52.9 ± 10.9	61.4 ± 11.1	68.0 ± 8.5	54.2 ± 8.9†
BMI, kg/m^2	23.4 ± 3.1	23.5 ± 2.8	23.2 ± 3.8	22.9 ± 3.3	23.9 ± 2.9	21.8 ± 3.4†

Values are mean ± SD. BMI, body mass index. *$P < 0.05$ between elderly group and younger group. †$P < 0.05$ between men and women.

Table 2. Body composition variables of the participants.

	Total elderly group (n = 60)	Non-frail (n = 34)	Pre-frail (n = 26)	Total younger group (n = 106)	Men (n = 55)	Women (n = 51)
FMBIA, %	29.0 ± 9.2*	28.6 ± 10.0	29.6 ± 8.2*	23.7 ± 7.3$^{\S *}$	19.7 ± 5.6*	28.1 ± 6.5*†
FMDXA, %	28.0 ± 8.8	28.0 ± 9.2	27.9 ± 8.6	25.4 ± 7.9§	21.6 ± 6.5	29.5 ± 7.2†
FMBIA, kg	16.6 ± 6.4*	15.2 ± 6.8	18.4 ± 5.6*	14.7 ± 5.8$^{\S *}$	13.7 ± 5.0*	15.7 ± 6.4*
FMDXA, kg	15.5 ± 6.0	14.4 ± 6.5	16.9 ± 5.0	15.6 ± 6.1	14.9 ± 5.6	16.3 ± 6.6
FFMBIA, kg	39.7 ± 7.5*	40.9 ± 7.3*	38.1 ± 7.6	44.2 ± 8.7$^{\S *}$	51.5 ± 4.8*	36.3 ± 3.2*†
FFMDXA, kg	39.0 ± 7.2	40.0 ± 6.7	37.8 ± 7.7	42.6 ± 8.6	49.7 ± 5.0	34.9 ± 3.4†

Values are mean ± SD. BIA, bioelectrical impedance analysis; DXA, dual X-ray absorptiometry; FM, fat mass; FFM, fat free mass. $^{\S}P < 0.05$ between elderly group and younger group.*$P < 0.05$ between BIA and DXA. $^{\dagger}P < 0.05$ between men and women.

Table 3. Summary of simple regression analysis for FFM and FM by BIA compared to DXA.

	Total group (n = 60)	Non-frail (n = 34)	Pre-frail (n = 26)
Simple regression analysis (FFM)			
Slope	0.93	0.91	0.98
Intercept	1.95	2.9	0.4
r	0.97	0.98	0.97
R2	0.94	0.95	0.94
SEE	1.9	1.86	1.95
P	<0.01	<0.01	<0.01
Simple regression analysis (FM)			
Slope	0.89	0.91	0.88
Intercept	0.69	0.6	0.64
r	0.95	0.94	0.97
R2	0.91	0.89	0.95
SEE	2.23	2.39	2.02
P	<0.01	<0.01	<0.01

SEE = Standard error of estimate.

Figure 1a. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FFM in non-frail.

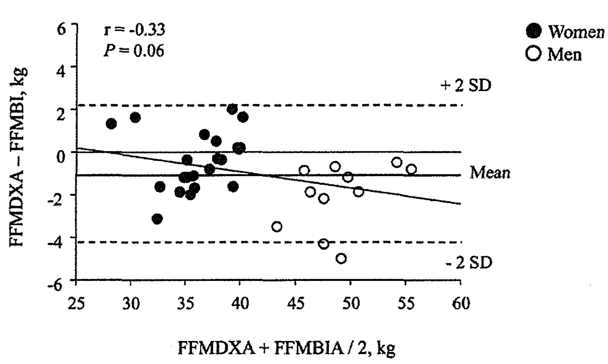


Figure 1b. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FFM in pre-frail.

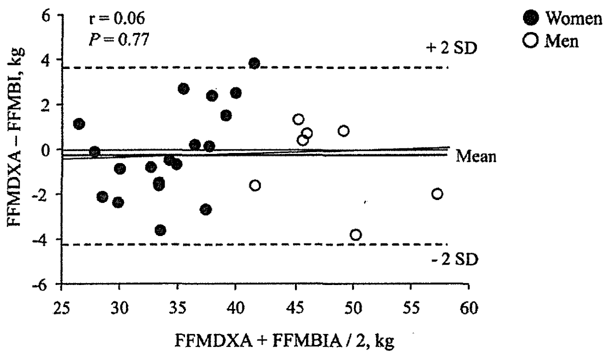


Figure 2a. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FM in non-frail.

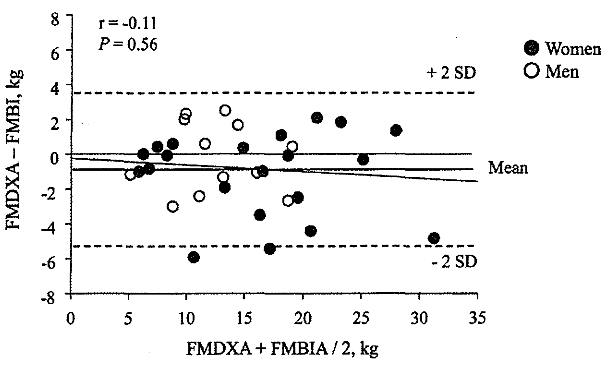
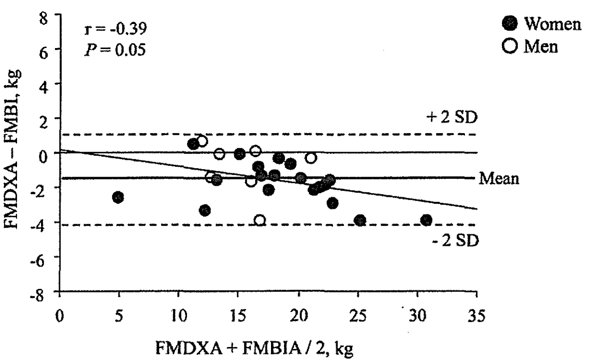


Figure 2b. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FM in pre-frail.



total group, r = 0.94 and r = 0.98 for non-frail, and r = 0.97 and r = 0.97 for pre-frail, respectively (all $P < 0.01$).

Figures 1a – 2b show results of the Bland-Altman plots for assessing bias in the estimation of FM and FFM between the two methods for both the non-frail and pre-frail groups. Bland Altman analysis reveals a tendency towards an increasing overestimation of FFMBIA with increasing FFM in the non-frail group (Figure 1a) and an overestimation of FMBIA with increasing FM in the pre-frail group (Figure 2b). The numbers for each bias (mean and 95% confidence interval (CI)) is as follows: -0.97, -1.53 0.40 for FFM in non-frail; -0.26, -1.06 0.53 for FFM in pre-frail; -0.80, -1.61 0.01 for FM in non-frail; -1.54, -2.08 -1.00 for FM in pre-frail, respectively.

In multiple regression analyses (data not shown), sex and frailty status were significant predictors (P = 0.05) for the bias between DXA and BIA Sex accounted for 3.9% (adjusted R2 = 0.039) in FM, and 7.2% (adjusted R^2 = 0.072) in FFM of the bias. Frailty status accounted for 2.0% (adjusted R^2 = 0.020) in FM, and 2.2% (adjusted R^2 = 0.022) in FM of the bias.

We conducted Pearson's product moment correlations for BIA and DXA for the healthy adults group aged 20-64 (not shown). The DXA method-derived body composition parameters correlated significantly with the BIA body composition parameters in this group (FM: r = 0.93, FFM = 0.98, $P < 0.01$, respectively). Bland-Altman analysis showed no significant bias in FFMBIA (r = -0.03, $P = 0.73$), whereas FMBIA tended to be overestimated with increasing FM (r = -0.27, $P = 0.05$). In addition, almost all individual plots for both FM and FFM were within 95% limits of agreement (mean and 95% CI: 0.91, 0.56 1.26 for FM; (0.34, -0.08 0.75 for 20-40yr; 1.54, 1.00 2.09 for 41-64yr); -0.26, -0.58 0.06 for FFM, respectively).

Discussion

In the present study, we examined whether bioelectrical impedance analysis (BIA) could accurately estimate body composition in older adults, including pre-frail older adults, using DXA as a reference method. This study showed excellent correlation between the two methods: both BIA and DXA can estimate body composition, not only in healthy adults but also in older adults, even in pre-frail older adults. However, using the Bland-Altman analysis, we also demonstrated that FM showed a tendency towards an overestimation of FM.

Many studies have reported that BIA is an adequate method for evaluating body composition in young people [17,18] However, the applicability of the BIA in older adults has been controversial [19] because aging is related to changes in height, weight and fat distribution [25]. In this study, we showed that excellent correlation between BIA and DXA both elderly group (non-frail and pre-frail) and younger group in all body composition parameters. However, in the Bland-Altman analyses, FM showed a tendency towards an overestimation of FM in younger group and pre-frail (elderly group).The mean bias and 95% CI of FM was 0.91 (0.56 – 1.26) in younger group, (0.34, -0.08 0.75 for 20-40yr; 1.54, 1.00 2.09 for 41-64yr), -1.12 (-1.63 – -0.62) in elderly group, -0.80 (-1.61 – 0.01) in non-frail, and -1.54 (-2.08 – -1.00) in pre-frail, respectively. Regarding FFM, the mean bias was lower in younger group (-0.26, -0.58 0.06) than elderly group (-0.66 -1.12 – -0.19). No systematic bias observed in Bland-Altman analyses in younger group, though a tendency of overestimation of FFM was found in non-frail (elderly group). It might be suggested that BIA can be assessed body composition at the same level in both younger and elderly groups.

In elderly group, although we confirmed a strong correlation between FFM and FM measured by BIA and DXA even in pre-frail older adults, our Bland-Altman analyses showed the BIA tended to overestimate and have a systematic bias for FM in pre-frail older adults compared to the DXA method. Also, there was a tendency for the BIA to overestimate FFM in non-frail older adults, though we found no systematic bias. The mean bias was -0.97 (-1.06 – -0.40) in non-frail, -0.26 (-1.06 – 0.53) in pre-frail for FFM, -0.80 (-1.61 – 0.01) in non-frail, -1.54 (-2.08 – -1.00) in pre-frail for FM, respectively. That is, while BIA may be more accurate in non-frail than pre-frail when estimating FM, BIA may evaluate FFM both non-frail and pre-frail in equal measure. BIA measurements for FM should be interpreted with caution in pre-frail older adults.

Regarding FM, previous studies on the validity of BIA in elderly people have demonstrated conflicting results. Vilaça et al. [26] showed that a single-frequency BIA (8 electrodes) may not support assessment of FFM and FM in undernourished older people using DXA as a reference method. They reported that a single-frequency BIA method tended to overestimate FFM and underestimate FM in 21 undernourished people aged 66-91. Although Völgyi et al., [27] showed the validity of BIA compared with DXA in Finnish people aged 37-81, they also found that BIA (a single-frequency, 8 electrode) underestimated body fat. By contrast, Mally et al. [28] indicated that segmental BIA (8 electrodes) overestimated FM in the trunk of 40 older European men aged 60-83. Sun et al. [29] also reported that the BIA (4 electrodes) tended to overestimate %FM in lean subjects and underestimate %FM in obese or overweight subjects aged 19-60. In addition, Kim et al. [30] revealed that the eight-electrode BIA led to an overestimation of body fat in lean men and an underestimation of body fat in obese women in Korean adults aged 20-88.

Our results which showed overestimation of FM are in accordance with those obtained by Sun et al. [29] and Kim et al. [30] when they assessed FM of lean subjects. In our study population, the prevalence of underweight (BMI value below 18.5 kg/m^2 [31]) in pre-frail (11.5%) was higher than non-frail (2.9%). Since we have determined if older adults are frail by the Fried's definition which includes weight loss criteria [1], pre-frail older adults may be relatively lean. In addition, concerning the bias, frailty status (2.0%, adjusted R2 = 0.020) was associated with the bias for FM as a result of multiple linear regression analysis. This condition might lead to the overestimation of FM in pre-frail older adults, as well as previous studies. Furthermore, we explored possible reason for the overestimation of FM by BIA in pre-frail. In general, older people are more susceptible to dehydration than younger people [32]. Dehydration is a common condition in the elderly [33]. Dehydration tends to cause FM to be overestimated. Yamamoto and Moshiki [34] showed that %total body water (TBW) was approximately 50 % in Japanese elderly aged over 60 years. The percentage of %TBW less than 50% in our subjects was 36% for non-frail, and 46% for pre-frail. It might be suggested that high prevalence of low %TBW compared with non-frail was related to overestimation of FM in pre-frail. Other potential reason for overestimation of FM may be the accuracy of measurement by DXA. We used DXA as a reference method as many researchers did. (e.g. [15,25]). However, Snead et al. [35] reported that DXA estimated 96% of exogenous fat of legs, but only 55% of trunk. Therefore, DXA underestimated truncal FM. That is, the observed overestimation of FM by BIA in pre-frail might also partly result from an underestimation of FM by DXA.

To our knowledge, this is the first study assessing the ability of BIA to detect body composition in the pre-frail population using DXA as a reference method. Frailty in older adults has become an important topic since frail elderly are highly vulnerable, which can lead to adverse health outcomes [1]. In addition, although the elderly subjects of our study tended to be normal weight rather than under/overweight (underweight: 6.6%, normal weight: 56.7%, overweight: 36.7%, respectively in our subjects) [31], frail people are at high risk of sarcopenic-obesity, which may lead to greater functional impairment. Therefore, it is important to investigate the validity of BIA for determining body composition in frail older adults.

Our study had several limitations. First, our results may not be representative of the population because our subjects had to be mobile enough to attend the study center, which may indicate selection bias and limit the generalizability of the results. We also had a limited sample size, although participants were chosen via particular inclusion criteria. Second, we used DXA as the reference method for body composition analysis; however, the DXA method may lead to some errors [36,37]. These limitations could be overcome with a multi-compartmental model of human composition [38].

In conclusion, the results of this study suggest that BIA can accurately estimate body composition, not only in healthy adults but also in non-frail and pre-frail older adults, although BIA measurements for FM may be interpreted with caution in pre-frail older adults. The BIA could be a convenient and practical approach for assessing body composition in clinical settings.

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Authors contribution: The study was accomplished through the University of Tsukuba. Also, the manuscript was written in collaboration with several co-authors, all of whom contributed to and approved its content. The contributions of each author were as follows: Ms. Nemoto, Drs. Yabushita, Kim, and Matsuo contributed to manuscript writing, developing study concept and design, data acquisition, and data analysis; Mr. Seino and Ms. Jung contributed to manuscript revisions, and data analysis; Dr. Sasai contributed to manuscript revisions, developing study concept and design, and data analysis; Dr. Tanaka represented the University of Tsukuba, contributed to manuscript revisions, developing study concept and design, and data acquisition.

Conflict of interest statement: We have no conflict of interest to disclose.

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Is a composite score of physical performance measures more useful than usual gait speed alone in assessing functional status?

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ABSTRACT

Overall physical performance can be represented by a composite score that is derived from upper and lower extremity performance measures. We aimed to identify whether composite scores of performance measures, particularly the lower extremity performance (LEP) score, upper extremity performance (UEP) score, and an overall score, are more accurate than usual gait speed (UGS) for assessing a wide range of functional status. We conducted a cross-sectional analysis on data from 701 community-dwelling older women (mean age 74.3 years). Trained testers measured UGS and the seven tests included in the composite scores. Using self-reported questionnaires, we assessed multiphasic functional status: physical function, higher-level functional capacity, mobility limitation, activities of daily living (ADLs), and falls. We compared the areas under the receiver operating characteristic curves (AUCs) of UGS with LEP, UEP, and overall scores for each status. We found no significant differences between the AUCs of UGS and LEP score for each status. The UEP score had significantly smaller AUCs for low physical function (0.73) and mobility limitation (0.78) than UGS alone (0.81 and 0.85, respectively), and the differences were substantial. Although the overall score had significantly greater AUCs for low higher-level functional capacity (0.83) and ADLs disability (0.83) than UGS alone (0.78 and 0.80, respectively), the differences were only 3–5%. The UGS should not be regarded solely as a measure of lower extremity function; this single test may represent overall physical performance. The UGS alone, which can be measured quickly and easily, suffice for assessing a wide range of functional status in older women.

1. Introduction

Performance-based measures of physical function not only represent a decline of functional status (e.g., functional limitation and disability), but also predict other adverse-health outcomes (e.g., hospitalization, institutionalization, and mortality) (Guralnik et al., 1994, 1995, 2000; Gill et al., 1995; Rantanen et al., 2003; Sayer et al., 2006; Cesari et al., 2009). Notably, LEP measures, such as UGS, are effective at predicting adverse-health outcomes (Cesari et al., 2005). A systematic review and meta-analysis by Cooper et al. (2010) explored associations between physical performance measures and all-cause mortality in community-dwelling older adults. The summary hazard ratio for mortality, when comparing the best 25% with the worst 25% of UGS scores was 2.87 (five studies, 14,692 participants). The hazard ratio for mortality was the greatest among the major performance measures.

Thus, it has been increasingly clear that an individual performance measure can contribute significantly to discerning functional status and adverse-health outcomes. However, a composite score that encompasses a wider spectrum of functional ability may capture more manifestations of disability. In fact, Cooper et al. (2011) have mentioned the necessity of investigating whether a derived composite score representing overall lower or upper body functioning, such as the short physical performance battery (SPPB) score (Guralnik et al., 1994) is a stronger predictor of health problems than any of the individual measures.

Guralnik et al. (2000) have concluded that UGS alone, which is a part of the SPPB, performed as well as the full SPPB in predicting incident disability, although there is a 3–5% difference between AUCs of the full battery and the UGS alone. Onder et al. (2005) calculated a summary performance score for lower extremities (score range, 0–2.71) from UGS, chair stand test, and balance tests which were included in the SPPB. They demonstrated that UGS was nearly as good as their lower extremity summary performance

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score in predicting incident disability. These studies revealed that the predictive abilities of UGS and SPPB for disability were almost the same.

We can hypothesize that an overall composite score which includes both upper and lower extremity performance measures can more accurately discriminate a wide range of functional status than UGS alone because of the following: (1) the LEP composite score and the UGS alone had the same predictive ability in the previous studies described above; (2) Hazuda et al. (2005) have shown that their UEP battery of testing makes an independent contribution beyond the SPPB in explaining disability and dependence.

The purpose of this study was to identify whether composite scores of performance measures, in particular, LEP score, UEP score, and overall score, are more sensitive than UGS alone in assessing a wide range of functional status in community-dwelling older women, including low physical function, low higher-level functional capacity, mobility limitation, disability, and falls.

2. Methods

2.1. Participants

A total of 763 community-dwelling older Japanese women (average age of 74.9 years) participated in this study. The participants were recruited from the towns of Ibaraki, Chiba, and Fukushima, Japan, between 2006 and 2010, as part of a nursing care prevention program or day-care service. Almost all the participants were recruited through local advertisements and flyers. The eligibility criteria were as follows: (1) community dwellers aged 65 years or older; and (2) ability to understand the instructions of performance tests and questionnaires. Participants who were unable to perform the tests safely and participants with data missing from their performance tests were excluded. The remaining 701 participants (average age of 74.3 years) included in this study ranged in age from 65 to 96 years. All participants provided written informed consent. We conducted this study in accordance with the guidelines proposed in the Declaration of Helsinki, and the study protocol was approved by the Ethics Committee of the University of Tsukuba, Japan.

2.2. Measurements

2.2.1. UGS

Participants were instructed to stand with their feet behind and just touching a starting line marked with tape at 0 m and, on receiving the tester's command, to start walking at their normal pace along a 7-m course. The actual walking speed was measured over 5-m starting with the first footfall past the 1-m mark and ending with the first footfall after the 6-m mark. Participants performed two trials with results averaged to the nearest 0.01 m/s (Shinkai et al., 2000). The reliability of UGS was excellent, with an intraclass correlation coefficient (ICC) of 0.97.

2.2.2. LEP score, UEP score, and overall score

We used a composite score equation for LEP that was previously developed along with a principal component analysis as a LEP indicator (Seino et al., 2009). The aim of using the LEP score was to identify individuals at a high risk of frailty based on Japan's long-term care insurance system (Tsutsui and Muramatsu, 2007). The tests included in the LEP score are tandem stance (Rossiter-Fornoff et al., 1995), chair stand test (Guralnik et al., 1994), alternate step (Menz and Lord, 2001), and timed up-and-go (Podsiadlo and Richardson, 1991). We selected these measures for their significant relevant factors for high risk of frailty based on Japan's long-term care insurance system after examining, with logistic regression analysis, twelve performance-based measures related to ADLs (Seino et al., 2009). The LEP score is distributed with a mean of 0 and a standard deviation (SD) of 1.0. The LEP score can be calculated with the following equation: LEP score = $0.031X_1 - 0.106X_2 - 0.192X_3 - 0.096X_4 + 1.672$, where X_1 = tandem stance (s), X_2 = chair stand test (s), X_3 = alternate step (s), X_4 = timed up-and-go (s). This equation was made in a weighted manner using the coefficients of principal component scores obtained from the principal component analysis. This analysis can provide the first principal component which accounts for the largest variance among the extracted components. The first principal component is a useful statistical tool combining all of the explanatory variables into a single expression (Nakamura et al., 1988). Since the first principal component represents a linear combination of tandem stance, 5 chair sit-to-stands, alternate step, and timed up-and-go, this component can be used as an overall index of LEP measures. This method has been described in more detail elsewhere (Nakamura et al., 1988, 1989, 1990; Shigematsu and Tanaka, 2000; Tanaka et al., 2000; Nakamura and Miyao, 2008).

By using a method similar to our construction of the LEP score equation, we obtained equations for an UEP score and overall score. The UEP score comprised hand-grip strength, manipulating pegs in a pegboard, and functional reach. The overall score comprised all the tests included in both the LEP score and UEP score equations. These scores are calculated as follows: UEP score = $0.091X_1 + 0.063X_2 + 0.061X_3 - 5.901$, where X_1 = hand-grip strength (kg), X_2 = manipulating pegs in a pegboard (number of pegs), X_3 = functional reach (cm); Overall score = $0.036X_1 + 0.040X_2 + 0.026X_3 + 0.015X_4 - 0.063X_5 - 0.117X_6 - 0.059X_7 - 1.746$, where X_1 = hand-grip strength (kg), X_2 = manipulating pegs in a pegboard (number of pegs), X_3 = functional reach (cm), X_4 = tandem stance (s), X_5 = chair stand test (s), X_6 = alternate step (s), X_7 = timed up-and-go (s).

2.2.2.1. Tandem stance. Participants stood with the heel of one foot directly in front of the toes of the other foot for a maximum of 30 s. The end point occurred when the participants shifted from the tandem position lifted or replaced a foot, moved a foot on the floor, or touched any object with their hands to maintain their balance (Rossiter-Fornoff et al., 1995). Participants performed two trials with the results averaged to the nearest 0.01 s. The reliability of the tandem stance was acceptable with an ICC of 0.80.

2.2.2.2. Chair stand test. The chair stand test measures the time to move from a sitting to a standing position 5 times without using the arms. Participants were asked to stand up and sit down on a straight-backed chair 46 cm high as quickly as possible. The time was measured from the initial sitting position to the final fully erect position at the end of the fifth stand (Guralnik et al., 1994). Participants performed two trials, and the results were averaged to the nearest 0.01 s. The reliability of the chair stand test was excellent with an ICC of 0.95.

2.2.2.3. Alternate step. Participants were asked to step with alternate feet onto a raised platform. The time it took to place each foot alternately onto a 19 cm high step 8 times was measured (Menz and Lord, 2001). Participants performed two trials, and the results were averaged to the nearest 0.01 s. The alternate step had an excellent reliability with an ICC of 0.96.

2.2.2.4. Timed up-and-go. Participants were asked to rise from a 46 cm high chair, walk forward 3 m as quickly as possible, turn 180°, walk back to the chair, and sit down (Podsiadlo and Richardson, 1991). Participants performed two trials with the results averaged to the nearest 0.01 s. The reliability of the timed up-and-go was excellent with an ICC of 0.99.

2.2.2.5. Hand-grip strength. We measured hand-grip strength using a hand-held dynamometer (GRIP-D, T.K.K 5401; Takei Scientific Instruments, Tokyo, Japan). Participants were in a standing position with their arms hanging naturally at their sides. They were instructed and verbally encouraged to squeeze the hand-grip as hard as they could. Grip size was adjusted to a comfortable level for the participant. Participants performed two trials with each hand alternately, and the results were averaged to the nearest 0.1 kg. The reliability of the hand-grip strength was excellent, with an ICC of 0.95.

2.2.2.6. Manipulating pegs in a pegboard. For this test, we used a pegboard (hand working test instrument, T.K.K 1306; Takei Scientific Instruments, Tokyo, Japan) consisting of 48 pegs arranged in a six-by-eight matrix on the side of the board distal to where the participants stood. With the board situated close to and at the midline of the body, participants were instructed to manipulate the pegs as fast as possible, one by one, using both hands, from the far side of the board to the near side. We recorded the number of pegs relocated within 30 s during 1 trial (Shigematsu and Tanaka, 2000). Shigematsu and Tanaka (2000) demonstrated an ICC with the manipulating pegs in a pegboard test of 0.82.

2.2.2.7. Functional reach. According to the measuring method devised by Duncan et al. (1992), participants stood with their feet together, their bodies perpendicular to and with one shoulder adjacent to, but not touching, a wall which had a measuring yardstick affixed to it horizontally. They raised their arms in front of them to a horizontal position with their tips of the middle fingers positioned at the zero end of the measuring yardstick. They reached forward as far as possible, bending as necessary but keeping their arms straight and horizontal and their feet in the starting position. The distance from beginning position to ending position as measured at the tips of the middle fingers was the functional reach value. We measured functional reach two times and recorded the average to the nearest 1 cm. Although the functional reach test was originally developed as a measure of dynamic balance, it involves movement of the upper extremities and is required for many upper body tasks (Hazuda et al., 2005). The reliability of functional reach was excellent, with an ICC of 0.94.

2.2.3. Functional status

We looked at 5 levels of functional status: physical function, higher-level functional capacity, mobility limitation, ADLs disability, and falls. We assessed these in our participants using several criteria and indices including the physical function index (PFI) of the Medical Outcomes Study 36-item Short-Form Health Survey (SF-36) (Ware and Sherboume, 1992), the Tokyo Metropolitan Institute of Gerontology (TMIG) index of competence (Koyano et al., 1991), and questions on mobility limitation, ADLs disability, and any falls in the previous year.

The PFI is derived from 10 items in the SF-36 that assess whether a participant's health limits her ability to perform vigorous activities such as running; moderate activities such as vacuuming; lifting or carrying groceries; climbing several sets of stairs; climbing one set of stairs; bending, kneeling, or stooping; ability to walk various distances without difficulty; and self-care. Each item is scored according to whether a person's health does not limit the activity (10 points), limits it a little (5 points), or limits it a lot (0 points). Possible scores range from 0 to 100 with higher scores indicating better physical function. We considered a PFI score of less than 70 points as a determiner of low physical function (Studenski et al., 2003).

We used the TMIG index to assess higher-level functional capacity (Koyano et al., 1991). On the basis of Lawton's hierarchical model of behavioral competence (Lawton, 1972), the TMIG index of competence was developed to assess levels of functional competence greater than those required for ADLs, such as instrumental ADLs (IADLs), intellectual activity, and an individual's social role (Koyano et al., 1991; Ishizaki et al., 2000; Fujiwara et al., 2003a). The response to each item in this multidimensional, 13-item index of competence is either 'yes' (able to perform) for 1 point or 'no' (unable to perform) for 0 points. The total score is the sum of the 13 items with a total score less than 11 defined as a low higher-level functional capacity (Fujiwara et al., 2003b).

We identified mobility limitations through face-to-face interviews on a participant's self-reported difficulty in walking one-quarter of a mile or climbing 10 steps without resting (Guralnik et al., 1993). Participants were asked the following questions: "Can you walk one-quarter of a mile without resting?" and "Can you climb 10 steps without assistance?" The response options were "no difficulty", "some difficulty", or "inability" to perform. Those who reported at least some difficulty performing these activities were rated as having limited mobility (Kim et al., 2009).

ADLs disability was assessed using selected ADLs (Mahoney and Barthel, 1965). The ADLs include aspects of eating, moving from bed to chair, grooming, toilet use, bathing, ambulation, negotiating stairs, dressing, and emptying bowels and bladder. We defined a participant as having an ADLs disability if she was unable to perform or needed human help with one or more ADLs tasks.

Information on falls was obtained through face-to-face interviews. We asked the following questions: "Have you fallen in the past year?" A fall was defined as an unintentional change in position resulting in coming to rest on the ground or other lower level (Kellogg International Work Group on the prevention of falls by the elderly, 1987).

2.2.4. Potential confounders

Several potential confounders were included in our analyses: age; body mass index (BMI), defined as body weight divided by height squared (kg/m^2); frequency of weekly outings; clinical conditions (history of stroke, hypertension, diabetes mellitus, heart disease, respiratory disease, and dyslipidemia); and joint pain (presence of low-back pain, or knee pain). All of these were computed on the basis of self-reported questions.

2.3. Statistical analyses

We used descriptive statistics to characterize the study participants, and we performed multiple logistic regression analyses to evaluate whether UGS and the LEP score, UEP score, and overall score were significantly associated with any of our functional status. Cesari et al. (2005) demonstrated that the prognostic value of UGS for identifying people at high risk of health-related outcomes was 1.0 m/s. In our analyses, we used the 1.0 m/s cut-off value to dichotomize UGS into high- and low-performance groups. The LEP score, UEP score, and overall score were dichotomized using the same percentile (22.7%) as the chosen UGS cut-off value. We determined this percentile based on the distribution of the present study sample population. By choosing this same threshold to identify individuals at a low-performance level, we determined equal distributions of the performance measures of interest, consequently allowing fair comparisons (Cesari et al., 2009). We adjusted for potential confounders and calculated the odds ratio (OR) and 95% confidence interval (95% CI) for each functional status according to our two categories: the high-performance category, which we considered a reference group; and the low-performance category.

To compare the discriminating power of UGS, LEP score, UEP score, and overall score for each functional status, we conducted receiver operating characteristic (ROC) analyses. Areas under the