18 Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 1991; **39**: 142–148.
19 Seino S, Yabushita N, Kim MJ *et al.* [A functional fitness test battery for pre-frail older adults (so-called "specified elderly individuals")]. *Jpn J Publ Health* 2009; **56**: 724–736. (In Japanese with an English abstract.)
20 Tsutsui T, Muramatsu N. Japan's universal long-term care system reform of 2005: containing costs and realizing a vision. *J Am Geriatr Soc* 2007; **55**: 1458–1463.
21 Nakamura E, Miyao K, Ozeki T. Assessment of biological age by principal component analysis. *Mech Ageing Dev* 1988; **46**: 1–18.
22 Nakamura E, Moritani T, Kanetaka A. Biological age versus physical fitness age. *Eur J Appl Physiol Occup Physiol* 1989; **58**: 778–785.
23 Nakamura E, Moritani T, Kanetaka A. Biological age versus physical fitness age in women. *Eur J Appl Physiol Occup Physiol* 1990; **61**: 202–208.
24 Nakamura E, Miyao K. Sex differences in human biological aging. *J Gerontol A Biol Sci Med Sci* 2008; **63**: 936–944.
25 Tanaka K, Shigematsu R, Nakagaichi M, Kim H, Takeshima N. The relationship between functional fitness and coronary heart disease risk factors in older Japanese adults. *J Aging Phys Act* 2000; 7: 162–174.
26 Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. *Md State Med J* 1965; **14**: 61–65.
27 Hauer K, Lamb SE, Jorstad EC, Todd C, Becker C. Systematic review of definitions and methods of measuring falls in randomised controlled fall prevention trials. *Age Ageing* 2006; **35**: 5–10.
28 Coussement J, De Paepe L, Schwendimann R, Denhaerynck K, Dejaeger E, Milisen K. Interventions for preventing falls in acute- and chronic-care hospitals: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008; **56**: 29–36.
29 Orme JG, Reis J, Herz EJ. Factorial and discriminant validity of the Center for Epidemiological Studies Depression (CES-D) scale. *J Clin Psychol* 1986; **42**: 28–33.
30 Fried LP, Tangen CM, Walston J *et al.* Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci* 2001; **56**: M146–M156.
31 Koyano W, Shibata H, Nakazato K, Haga H, Suyama Y. Measurement of competence: reliability and validity of the TMIG Index of Competence. *Arch Gerontol Geriatr* 1991; **13**: 103–116.
32 Fujiwara Y, Shinkai S, Amano H *et al.* [Test-retest variation in the Tokyo Metropolitan Institute of Gerontology Index of Competence in community-dwelling older people independent in daily living toward individual assessment of functional capacity]. *Jpn J Publ Health* 2003; **50**: 360–367. (In Japanese with an English abstract.)
33 Kim H, Yoshida H, Suzuki T. The effects of multidimensional exercise on functional decline, urinary incontinence, and fear of falling in community-dwelling elderly women with multiple symptoms of geriatric syndrome: a randomized controlled and 6-month follow-up trial. *Arch Gerontol Geriatr* 2011; **52**: 99–105.
34 DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988; **44**: 837–845.
35 Hosmer DW, Lemeshow S. *Applied Logistic Regression*. New York: John Wily & Sons, Inc., 2000.
36 Cesari M, Kritchevsky SB, Penninx BW *et al.* Prognostic value of usual gait speed in well-functioning older people–results from the Health, Aging and Body Composition Study. *J Am Geriatr Soc* 2005; **53**: 1675–1680.
37 Cesari M, Kritchevsky SB, Newman AB *et al.* Added value of physical performance measures in predicting adverse health-related events: results from the Health, Aging And Body Composition Study. *J Am Geriatr Soc* 2009; **57**: 251–259.
38 Wilson PW, Nam BH, Pencina M, D'Agostino RB, Sr, Benjamin EJ, O'Donnell CJ. C-reactive protein and risk of cardiovascular disease in men and women from the Framingham Heart Study. *Arch Intern Med* 2005; **165**: 2473–2478.
39 Walldius G, Jungner I, Holme I, Aastveit AH, Kolar W, Steiner E. High apolipoprotein B, low apolipoprotein A-I, and improvement in the prediction of fatal myocardial infarction (AMORIS study): a prospective study. *Lancet* 2001; **358**: 2026–2033.
40 Kattan MW, Shariat SF, Andrews B *et al.* The addition of interleukin-6 soluble receptor and transforming growth factor beta1 improves a preoperative nomogram for predicting biochemical progression in patients with clinically localized prostate cancer. *J Clin Oncol* 2003; **21**: 3573–3579.
41 Norman K, Stobaus N, Gonzalez MC, Schulzke JD, Pirlich M. Hand grip strength: outcome predictor and marker of nutritional status. *Clin Nutr* 2011; **30**: 135–142.
42 Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol* 2000; **89**: 81–88.
43 Ishizaki T, Furuna T, Yoshida Y *et al.* Declines in physical performance by sex and age among nondisabled community-dwelling older Japanese during a 6-year period. *J Epidemiol* 2011; **21**: 176–183.
44 Viccaro LJ, Perera S, Studenski SA. Is timed up and go better than gait speed in predicting health, function, and falls in older adults? *J Am Geriatr Soc* 2011; **59**: 887–892.
45 Montero-Odasso M, Schapira M, Soriano ER *et al.* Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older. *J Gerontol A Biol Sci Med Sci* 2005; **60**: 1304–1309.
46 Ferrucci L, Bandinelli S, Benvenuti E *et al.* Subsystems contributing to the decline in ability to walk: bridging the gap between epidemiology and geriatric practice in the InCHIANTI study. *J Am Geriatr Soc* 2000; **48**: 1618–1625.
47 Studenski S, Perera S, Patel K *et al.* Gait speed and survival in older adults. *JAMA* 2011; **305**: 50–58.
48 Takahashi STM, Toriida M, Tayama H. A study on the standard of gait evaluation -by an actual investigation of crosswalks. *Rigaku Ryoho Gaku* 1989; **16**: 261–266. (In Japanese.)
49 Shinkai S, Watanabe S, Kumagai S *et al.* Walking speed as a good predictor for the onset of functional dependence in a Japanese rural community population. *Age Ageing* 2000; **29**: 441–446.
50 Skoog I. Psychiatric disorders in the elderly. *Can J Psychiatry* 2011; **56**: 387–397.

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

Miyuki Nemoto[1, 2], Noriko Yabushita[1], Mi-ji Kim[3], Tomoaki Matsuo[1], Satoshi Seino[1, 2], Songee Jung[1], Hiroyuki Sasai[4] and Kiyoji Tanaka[1]

[1]Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8577, Japan; [2]The Japan Society for the Promotion of Science, 8 Ichiban, Chiyoda, Tokyo 102-8472, Japan; [3]The Research Team for Promoting Independence of the Elderly, Tokyo Metropolitan Institute of Gerontology, 35-2 Sakae-cho, Itabashi-ku, Tokyo 173-0015, Japan; [4]Diabetes, Endocrinology, and Obesity Branch, National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Bethesda, Maryland 20892, USA.

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].

Address for correspondence: Miyuki Nemoto, MS, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8577, Japan
Tel: +81-29-853-2655 Fax: +81-29-838-5883
Email: n-miyuki@stat.taiiku.tsukuba.ac.jp

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/m²	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§*	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§*	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§*	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. §$P < 0.05$ between elderly group and younger group.*$P < 0.05$ between BIA and DXA. †$P < 0.05$ 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.

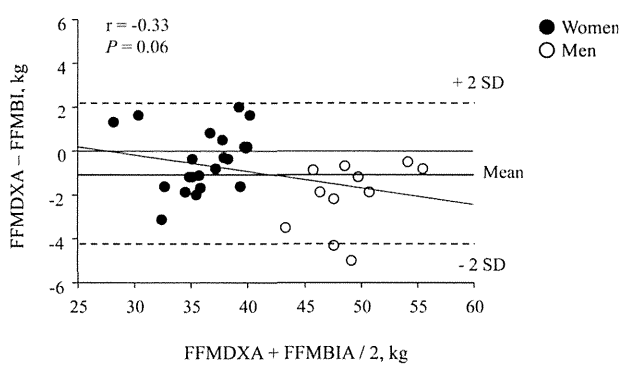


Figure 1b. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FFM in pre-frail.

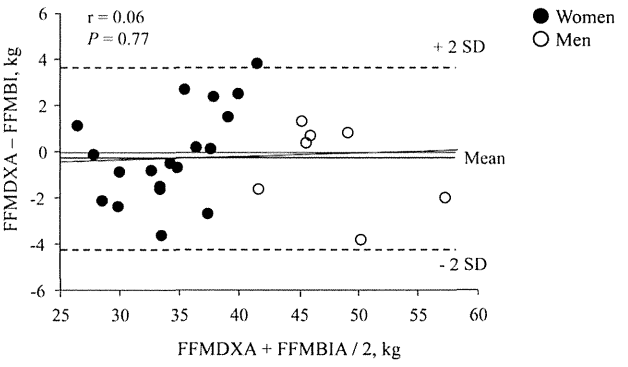


Figure 2a. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FM in non-frail.

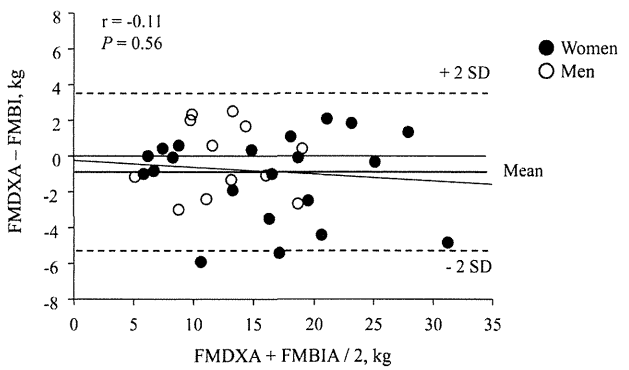
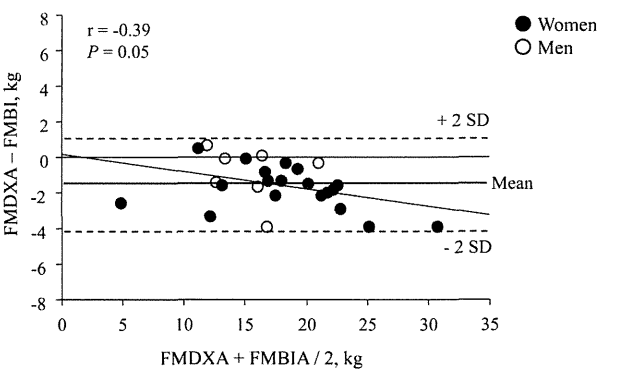


Figure 2b. Bland-Altman plot Bland-Altman plots for the systematic bias in the estimation of FM in pre-frail.



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.

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References

1. Fried LP, Tangen CM, Walston J, et al.Frailty in older adults: Evidence for a phenotype. J Gerontol A Biol Sci Med Sci 2001;56:M146-156.
2. St-Onge MP. Relationship between body composition changes and changes in physical function and metabolic risk factors in aging. Curr Opin Clin Nutr Metab Care 2005;8:523-528.
3. Baumgartner RN. Body composition in healthy aging. Ann N Y Acad Sci 2000;904:437-448.
4. Baumgartner RN, Wayne SJ, Waters DL, et al. Sarcopenic obesity predicts instrumental activities of daily living disability in the elderly. Obes Res 2004;12:1995-2004.
5. Rolland Y, Lauwers-Cances V, Cristini C, et al. Difficulties with physical function associated with obesity, sarcopenia, and sarcopenic-obesity in community-dwelling elderly women: The epidos (epidemiologie de l'osteoporose) study. Am J Clin Nutr 2009;89:1895-1900.
6. Cooper C, Dere W, Evans W, et al. Frailty and sarcopenia: Definitions and outcome parameters. Osteoporos Int 2012.
7. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European working group on sarcopenia in older people. Age Ageing 2010;39:412-423.
8. Hubbard RE, Lang IA, Llewellyn DJ, et al. Frailty, body mass index, and abdominal obesity in older people. J Gerontol A Biol Sci Med Sci 2010;65:377-381.
9. Andreoli A, Scalzo G, Masala S, et al. Body composition assessment by dual-energy x-ray absorptiometry (dxa). Radiol Med 2009;114:286-300.
10. Park YW, Heymsfield SB, Gallagher D. Are dual-energy x-ray absorptiometry regional estimates associated with visceral adipose tissue mass? Int J Obes Relat Metab Disord 2002;26:978-983.

11. Prior BM, Cureton KJ, Modlesky CM, et al. In vivo validation of whole body composition estimates from dual-energy x-ray absorptiometry. J Appl Physiol 1997;83:623-630.
12. Salamone LM, Fuerst T, Visser M, et al. Measurement of fat mass using dexa: A validation study in elderly adults. J Appl Physiol 2000;89:345-352.
13. Sopher AB, Thornton JC, Wang J, et al. Measurement of percentage of body fat in 411 children and adolescents: A comparison of dual-energy x-ray absorptiometry with a four-compartment model. Pediatrics 2004;113:1285-1290.
14. Bedogni G, Malavolti M, Severi S, et al. Accuracy of an eight-point tactile-electrode impedance method in the assessment of total body water. Eur J Clin Nutr 2002;56:1143-1148.
15. Ling CH, de Craen AJ, Slagboom PE, et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. Clin Nutr 2011;30:610-615.
16. Shafer KJ, Siders WA, Johnson LK, et al. Validity of segmental multiple-frequency bioelectrical impedance analysis to estimate body composition of adults across a range of body mass indexes. Nutrition 2009;25:25-32.
17. Gupta N, Balasekaran G, Victor Govindaswamy V, et al. Comparison of body composition with bioelectric impedance (bia) and dual energy x-ray absorptiometry (dexa) among singapore chinese. J Sci Med Sport 2011;14:33-35.
18. Pietrobelli A, Rubiano F, St-Onge MP, et al. New bioimpedance analysis system: Improved phenotyping with whole-body analysis. Eur J Clin Nutr 2004;58:1479-1484.
19. Roubenoff R, Baumgartner RN, Harris TB, et al. Application of bioelectrical impedance analysis to elderly populations. J Gerontol A Biol Sci Med Sci 1997;52:M129-136.
20. Genton L, Karsegard VL, Kyle UG, et al. Comparison of four bioelectrical impedance analysis formulas in healthy elderly subjects. Gerontology 2001;47:315-323.
21. Kim H, Tanaka K, Nakanishi T, et al. Multi-frequency bioelectrical impedance method: Assessment of body composition in japanese men and women over 60 years of age. Bulletin of Institute of Health and Sports Sciences, University of Tsukuba 1999;22:52-62.
22. Haapala I, Hirvonen A, Niskanen L, et al. Anthropometry, bioelectrical impedance and dual-energy x-ray absorptiometry in the assessment of body composition in elderly finnish women. Clinical physiology and functional imaging 2002;22:383-391.
23. Orme JG, Reis J, Herz EJ. Factorial and discriminant validity of the center for epidemiological studies depression (ces-d) scale. J Clin Psychol 1986;42:28-33.
24. Bland JM, Altman DG.. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-310.
25. Lupoli L, Sergi G, Coin A, et al. Body composition in underweight elderly subjects: Reliability of bioelectrical impedance analysis. Clin Nutr 2004;23:1371-1380.
26. Vilaca KH, Paula FJ, Ferriolli E, et al. Body composition assessment of undernourished older subjects by dual-energy x-ray absorptiometry and bioelectric impedance analysis. J Nutr Health Aging 2011;15:439-443.
27. Volgyi E, Tylavsky FA, Lyytikainen A, et al. Assessing body composition with dxa and bioimpedance: Effects of obesity, physical activity, and age. Obesity 2008;16:700-705.
28. Mally K, Trentmann J, Heller M, et al. Reliability and accuracy of segmental bioelectrical impedance analysis for assessing muscle and fat mass in older europeans: A comparison with dual-energy x-ray absorptiometry. Eur J Appl Physiol 2011;111:1879-1887.
29. Sun G, French CR, Martin GR, et al. Comparison of multifrequency bioelectrical impedance analysis with dual-energy x-ray absorptiometry for assessment of percentage body fat in a large, healthy population. Am J Clin Nutr 2005;81:74-78.
30. Kim H, Kim CH, Kim DW, et al. External cross-validation of bioelectrical impedance analysis for the assessment of body composition in korean adults. Nutrition research and practice 2011;5:246-252.
31. Physical status: The use and interpretation of anthropometry. Report of a WHO expert committee. Technical report series no. 854. Geneva, World Health Organization, 1995,
32. Schols JM, De Groot CP, van der Cammen TJ, et al. Preventing and treating dehydration in the elderly during periods of illness and warm weather. J Nutr Health Aging 2009;13:150-157.
33. Wotton K, Crannitch K, Munt R. Prevalence, risk factors and strategies to prevent dehydration in older adults. Contemporary Nurse 2008;31:44-56.
34. Yamamoto K, Nishiki M. Multi-frequency bioelectrical impedance method for the assessment of body composition in japanese adults Med J Hiroshima Univ 2000;48:259-266.
35. Snead DB, Birge SJ, Kohrt WM. Age-related differences in body composition by hydrodensitometry and dual-energy x-ray absorptiometry. J Appl Physiol 1993;74:770-775.
36. Van Loan MD. Is dual-energy x-ray absorptiometry ready for prime time in the clinical evaluation of body composition? Am J Clin Nutr 1998;68:1155-1156.
37. Van Loan MD, Mayclin PL. Body composition assessment: Dual-energy x-ray absorptiometry (dexa) compared to reference methods. Eur J Clin Nutr 1992;46:125-130.
38. Sun SS, Chumlea WC, Heymsfield SB, et al. Development of bioelectrical impedance analysis prediction equations for body composition with the use of a multicomponent model for use in epidemiologic surveys. Am J Clin Nutr 2003;77:331-340.

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

Satoshi Seino [a,b,*], Mi-ji Kim [c], Noriko Yabushita [a], Miyuki Nemoto [a], Songee Jung [a], Yosuke Osuka [a], Yoshiro Okubo [a], Tomoaki Matsuo [a], Kiyoji Tanaka [a]

[a] Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, Japan
[b] The Japan Society for the Promotion of Science, 8 Ichiban, Chiyoda, Tokyo 102-8472, Japan
[c] The Research Team for Promotion Independence of the Elderly, Tokyo Metropolitan Geriatric Hospital and Institute of Gerontology, 35-2 Sakae, Itabashi, Tokyo 173-0015, Japan

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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

* Corresponding author at: Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, Japan. Tel.: +81 29 853 5600x8365; fax: +81 29 853 2986.
E-mail address: se-no@stat.taiiku.tsukuba.ac.jp (S. Seino).

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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.