Table 2. Paired Comparison of Spatiotemporal Gait Parameters for Normal Walking and Dual-Task Walking

Variables	Normal Walking (*M* ± *SD*)	Dual-Task Walking (*M* ± *SD*)	Mean Difference (95% CI)	*p* Value	Adjusted *p* Value*
Gait speed (m/s)	1.10 ± 0.26	1.04 ± 0.31	−0.05 (−0.10, −0.01)	.022	.029†
Stride length (m)	1.13 ± 0.21	1.19 ± 0.41	0.06 (−0.01, 0.13)	.103	<.001
Cadence (steps/min)	115.8 ± 12.3	107.6 ± 17.8	−8.0 (−12.21, −3.80)	<.001	< .001
Harmonic ratio					
Vertical	2.84 ± 0.86	2.44 ± 0.81	−0.38 (−0.64, −0.12)	.005	<.001
Mediolateral	2.12 ± 0.65	1.95 ± 0.53	−0.19 (−0.36, −0.01)	.036	.002
Anteroposterior	3.13 ± 1.04	2.61 ± 0.83	−0.53 (−0.79, −0.25)	<.001	<.001

Notes: CI = confidence interval.

*Adjusted for sex and gait speed.

†Adjusted only for sex.

was observed in all three directions. However, the association between brain atrophy and DTC in HR was only present in VT direction.

Both the motor system and the cognitive system act reciprocally to ensure successful locomotion. To investigate this interaction, many experiments have been conducted using the dual-task method (10,11,12). DTC in gait parameters among older adults as a result of cognitive motor interference reflect an adaptation to a more challenging conditions and the fact that locomotion requires high-order cognitive processing such as executive function (5,6,7). Dual tasking generally affects spatiotemporal gait parameters including lower extremity (10,12) and trunk movement (7,13,14,15). Our results were consistent with reported dual-task changes for spatiotemporal gait measures, although the magnitude of changes varied among gait variables, type of tasks, or task difficulty (10,12). Dual tasking decreases HR as indicated by decreased smoothness of trunk movement and increased trunk instability in all directions. Furthermore, decreased HR may be caused by an adaptation because similar changes in HR have been reported for walking with additional challenges (eg, walking on an irregular surface) (4). The DTC in spatiotemporal gait parameters observed in our study suggest that dual tasking influences the control of both lower extremity and trunk movement.

Table 3. A Linear Regression Model for Brain Atrophy

	Brain Atrophy	
Variables	β (*SE*)	*p* Value
Age	.352 (.004)	<.001
Gender	.462 (.034)	<.001
Body mass index	.240 (.007)	.010
Educational history	−.028 (.010)	.779
Mini-Mental State Examination score	−.143 (.011)	.164
Grip strength	−.082 (.005)	.540
Tokyo Metropolitan Institute of Gerontology Index of Competence	.072 (.023)	.469
Geriatric Depression Scale	.249 (.008)	.016
Dual-task–related changes of HR in VT direction	.231 (.062)	.024
R^2		.362

Notes: HR = harmonic ratio; VT = vertical. A linear regression model was used to examine the association between dual-task–related changes of the gait parameter and brain atrophy, adjusted for gait speed.

MRI-based measures of brain atrophy are valid parameters because macrostructural brain abnormalities inevitably lead to neurodegeneration, neuropsychological deficits, tangle deposition, and microstructural loss (24). The macrostructural brain abnormalities associated with gait are hyperintensities of the white matter (19,20,21) and atrophy of the gray matter (21,22,23). The brain volume in the sensorimotor and frontoparietal regions including the prefrontal lobes is associated with step time and double support time during normal gait (22), and the differences between intracranial and brain volume were independently related to slower gait speed in women after adjusting for covariates (21). While one study reported that hippocampal volume is related to gait speed (23), results of another study suggest that gait performance among older adults is not necessarily related to atrophy in the memory domain including the hippocampus (22). The latter study also reported a weak association between gait measures and brain volume in the cerebellum or basal ganglia structures—regions that play key roles in the control of balance. A consensus has not been reached on the relationship between quantitative MRI-based measures of brain atrophy and gait variables. The results of our study indicate that DTC in trunk movement is significantly related to brain atrophy measured using the voxel-by-voxel method, which has been validated in other studies (26,27). Rosano and colleagues (22) suggested that gait variables under several conditions, including difficult conditions, should be investigated to clarify the task-specific network in the brain. Our initial results indicate that DTC in trunk movement might be associated with brain atrophy.

The control of trunk movement contributes to successful locomotion and is under continuous active neural control (1). The neural network may prioritize trunk stability to increase head stability during walking (35). Additionally, dual-task walking requires successful allocation of attention to both walking and the other task, which relies on executive function. In fact, dual-task decrements of gait measures are related to cognitive performance such as executive function (5,6,7), and both mobility and cognitive function are enhanced by dual-task intervention training as shown by results of randomized clinical trials (16,17). Because dual-task walking requires the simultaneous control of walking and an additional task, the demand on neural resources for postural adjustments during walking may be greater for dual-task walking compared with normal walking. The analysis of HR during dual-task walking revealed an association between DTC in HR and brain atrophy; however, there was no relationship between DTC in other gait variables and brain atrophy. These results suggest that HR during dual-task walking may be a biomechanical marker for identifying a decline in brain volume.

Although dual-task walking decreased HR for trunk movement in all directions, an association between brain atrophy and DTC in HR was only observed in VT direction. These observations agree with results of other studies that HR data for lower trunk acceleration may represent different phenomena depended on the direction (2,36). Menz and colleagues (2) reported that directional specificity in HR in older adults was greater while walking under more challenging conditions. Results of their study suggested that the HR value of the lower trunk in VT direction had the ability to detect instability under challenging conditions. In another study, Brach and colleagues (3) suggested that HR in anteroposterior direction represents age-related changes that are not even affected by gait speed. The directional specificity of HR was not fully clarified, and further evidence for this specificity is required. Nevertheless, the results of our study indicate that brain atrophy is more likely to be related to trunk instability in the VT direction than in the anteroposterior and mediolateral directions induced by dual-task walking.

One limitation of this study is the relatively small sample size. Additionally, some physical dimensions, such as fitness level (37) and static postural instability (38), may have acted as confounding factors but were not included in this study. Furthermore, the effects of executive function and attention as confounding factors could influence dual-task gait performance (6,12) and should be considered to generalize these results. Moreover, the type and/or difficulty of dual-task walking in this study could have affected the results. Hence, dual-task walking using other types of cognitive tasks (eg, verbal fluency) should further be investigated. Finally, in this study, we measured atrophy of the entire brain. It is likely that regional atrophy assessed by MRI and other macrostructural measures (eg, white matter lesions) will provide a better insight into the mechanistic relationship between brain atrophy and gait function.

CONCLUSION

Brain atrophy correlated with a decline in the control of trunk movement during dual-task walking. This result indicates that dual-task walking induces trunk instability because additional cognitive resources are required compared with that during normal walking. Further studies are needed to clarify the effects of regional structural brain loss on the control of trunk movement and limb control during walking.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Estimation of appendicular muscle mass and fat mass by near infrared spectroscopy in older persons

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Aim: Near infrared spectroscopy has been reported to have a high reliability and accuracy in assessing the percentage of body fat. However, whether muscle mass can be accurately estimated using this method has not been established. This study examined whether a near infrared spectroscopy method could estimate appendicular muscle mass and fat mass, with dual-energy X-ray absorptiometry as the standard method for comparison.

Methods: A total of 20 orthopedic inpatients (mean age 73.2 ± 6.8 years) were recruited for this study. Their body composition was assessed using near infrared spectroscopy and dual-energy X-ray absorptiometry. Appendicular muscle mass and fat mass were estimated from height, weight and optical densities.

Results: The optical densities for the upper arm (biceps, triceps) and forearm (flexor carpi radialis) were significantly correlated with appendicular muscle mass ($r = 0.534$ to 0.623) or fat mass ($r = -0.483$ to -0.827). Estimated appendicular muscle mass and fat mass explained 89% and 80% of the variance in the dual-energy X-ray absorptiometry-derived muscle mass and fat mass estimates using height, weight and optical density values of the proximal flexor carpi radialis.

Conclusions: Near infrared spectroscopy is a useful method to assess not only fat mass, but also muscle mass in older adults. **Geriatr Gerontol Int 2012; 12: 652–658.**

Keywords: aged, body composition, body fat, sarcopenia, skeletal muscles.

Introduction

Age-related loss of muscle mass (so-called sarcopenia) can lead to functional decline in older persons.[1–5] Two published Health, Aging and Body Composition reports showed that sarcopenia, as determined by computed tomography (CT) in the mid-thigh, was a weak to modest predictor of loss of physical function over the following 2 to 3 years.[6,7] Furthermore, one study reported that older sarcopenic patients were twice as likely to contract infection during a hospital stay compared with older patients with a normal muscle mass.[8] This suggested that sarcopenic individuals might have decreased immunity, which might provide a mechanistic link between sarcopenia and mortality risk. In addition, reduced arm muscle area was reported to be an independent predictor of long-term mortality in community-dwelling older adults.[9] According to the

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New Mexico Elder Health Survey, the prevalence of sarcopenia increased from 13 to 24% in persons aged under 70 years to >50% in persons aged over 80 years.[1] To achieve successful aging, it is important to preserve muscle mass to maintain function.

Recently, some researchers reported that sarcopenic patients who were obese were at particularly high risk of functional impairment and physical disability.[10–13] The condition was termed sarcopenic obesity, and it was suggested that approximately 15% of those with sarcopenia were also obese.[10] This suggests that it is necessary to assess not only muscle mass, but also fat mass accurately in the elderly.

There are various methods for measurement of body composition. Total body and regional skeletal muscle mass can now be accurately quantified using imaging methods, including CT and magnetic resonance imaging (MRI).[14] However, CT and MRI are costly methods and access to the equipment can be limited. Dual-energy X-ray absorptiometry (DXA) has been widely used in clinical practice, not only for osteoporosis screening and diagnosis, but also for assessment of body composition, such as skeletal muscle mass and fat mass. DXA is less expensive and less invasive compared with MRI and CT. Previous studies have shown good correlations between DXA-derived lean soft tissue mass and skeletal muscle mass in the lower limb region when CT and MRI were used as the standards for comparison.[15,16] However, DXA methods take more time, although whole-body scanning by this method exposes the patient to minimal radiation.

Bioelectrical impedance analysis (BIA) is a non-invasive, portable, quick and inexpensive method for measuring body composition.[17] Previous studies have shown that there is a strong correlation between BIA resistance and skeletal muscle measurements in the arms[18] and legs.[19] In addition, one report suggested that BIA could provide rapid and accurate estimates of whole body skeletal muscle mass in adults.[20] There are some disadvantages with the BIA method. First, fat tissue also holds water, although the proportion is small.[21] Second, the volume of muscle derived by BIA might overestimate the actual volume. Third, there are a large proportion of older adults who have a changed distribution of body water, such as edema. One report showed that the expansion of extracellular water relative to intracellular water and to regional lean volume masks actual muscle cell atrophy during aging.[22] This suggested that it might be difficult to accurately assess body composition in older adults.

Another development that might have potential for use in older adults is near infrared spectroscopy (NIRS). NIRS is also a non-invasive, simple and rapid method of assessing the percentage of body fat. There are some reports that the NIRS method has a high reliability and accuracy in determination of the percentage of body fat.[23–25] In contrast, it has not been established whether muscle mass can be estimated accurately by NIRS.

The present study investigated whether a NIRS method could provide an accurate estimate of appendicular muscle mass (AMM) and appendicular fat mass (AFM) using DXA as the standard method for comparison.

Methods

Participants

A total of 20 orthopedic patients who were admitted to the National Hospital for Geriatric Medicine and who were aged 60 years or older were recruited for the present study. Patients with dementia or who had major laterality of muscle mass in the arms and legs, or who had surgery just before the study were excluded. All participants had their height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) measured after admission. The details of the study were explained in advance and written consent was obtained from each participant. In addition, the present study was approved by the ethics committee of the National Center for Geriatrics and Gerontology.

Measurement of body composition

Whole and regional body composition was measured using DXA (Lunar DPX, Madison, WI, USA). This system provided the mass of lean soft tissue, fat and bone mineral for both the whole body and specific regions. Appendages were isolated from the trunk and head by using a DXA regional computer-generated default line. AMM or AFM was derived as the sum of the fat-free soft tissues or fat tissue of the arms and legs. A previous study reported that total body skeletal muscle mass can be accurately predicted from DXA-estimated appendicular lean soft tissue mass.[26,27]

NIRS

The NIRS measurements were carried out with the Fitness Analyzer BFT-3000 (Kett Electrical Laboratory, Tokyo, Japan, Fig. 1), the Japanese version of the Futrex 5000 (Futrex, Gaithersburg, MD, USA; 1988), which has potential for estimating body composition.[22,28] This device uses optical densities (OD) at two wavelengths (OD1 = 937 nm, OD2 = 947 nm) measured at each site. The NIRS instrument was tested immediately before taking measurements on each patients by using an optical standard, which was provided with the instrument and situated in a flexible light shield, to ensure that its performance was consistent throughout the study.

OD values were obtained at six sites: distal biceps (5 cm from the olecranon), distal triceps (5 cm from the

Figure 1 The near infrared spectroscopy instrument (Fitness Analyzer BFT-3000).

Figure 2 Method of measurement.

olecranon), proximal flexor carpi radialis (5 cm from the olecranon), distal quadriceps (5 cm from the upper edge of patella), proximal tibialis anterior (5 cm from the caput fibulae) and proximal calf (5 cm from the caput fibulae). The reliability was confirmed by test–retest. The test–retest reproducibility was excellent (intraclass correlation coefficient = 0.95–0.97, $P < 0.01$). Patients were required to maintain a seated position, with their arms relaxed at their sides (Fig. 2). NIRS measurements were carried out by a single trained physical therapist, and completed within a few minutes.

Statistical analysis

Pearson's correlation coefficient was used to determine the relationship between AMM or AFM and each OD value. Equations for estimation of AMM and AFM were developed with the use of multiple linear regression analysis. Potential explanatory variables included OD value, height and weight. DXA-measured AMM and AFM were set as the objective variable. The coefficient of determination (R^2) values were used to quantify the accuracy of model fit. The mean difference between DXA-measured AMM (AFM) and estimated AMM (AFM) was tested using the paired Student's *t*-test. Statistical analyses were carried out using PASW Statistics 18 for Windows (SPSS, Chicago, IL, USA) and the significance level was less than 5%.

Results

The characteristics of the patients are shown in Table 1. Mean age was 73.2 ± 6.8 years (range 62–84 years) and 70% were female. The subjects were diagnosed with the following: spinal canal stenosis ($n = 11$), disc herniation ($n = 1$), spinal tumor ($n = 2$), knee osteoarthritis ($n = 2$), compression fracture ($n = 1$), femoral neck fracture ($n = 1$) and others ($n = 2$).

The correlation coefficients between AMM or AFM and each OD value are listed in Table 2. AMM was significantly correlated with OD values at the distal triceps (OD1: $r = 0.623$; OD2: $r = 0.534$). AFM was significantly correlated with OD values at the distal biceps (OD1 $r = -0.570$; OD2 $r = -0.551$), distal triceps (OD1 $r = -0.483$; OD2 $r = -0.494$) and proximal flexor carpi radialis (OD1 $r = -0.827$; OD2 $r = -0.821$). In the correlation analysis between muscle mass or fat mass and the OD value, correlation coefficients were mostly higher with OD1 than with OD2. Thus, OD1 was used as the representative value of NIRS data for the estimation equation.

The results from linear regression analyses for the multivariate models are presented in Table 3. The multiple regression equations incorporated height, weight and OD1. Using anthropometric data (height and weight) as the explanatory variables, the R^2 value of AMM and AFM were 0.81 (standard error of the estimate [SEE] = 1.67 kg) and 0.50 (SEE = 1.77 kg), respectively (model 1). When OD1 was added to the explanatory variables, the R^2 values of AMM and AFM ranged from 0.85 to 0.89, and 0.58 to 0.80, respectively (models 2–5). The highest R^2 values of AMM and AFM were 0.89 (SEE = 1.33 kg) and 0.80 (SEE = 1.16 kg), respectively, when OD1 at the proximal flexor carpi radialis was added to the explanatory variables. For separate estimation equations (upper and lower limb), the accuracy of model fit was slightly less (muscle mass $R^2 = 0.82$–0.87, fat mass $R^2 = 0.53$–0.55). There were no significant differences between DXA-measured AMM and estimated AMM (mean difference 0.01, 95% confidence interval –0.56 to 0.58), or between DXA-measured AFM and estimated AFM (mean difference –0.25, 95% confidence interval –0.75 to 0.25).

Table 1 Physical characteristics of the study participants

Variables	All subjects ($n = 20$)	Men ($n = 6$)	Women ($n = 14$)
Age (years)	73.2 ± 6.8	67.8 ± 8.1	75.5 ± 4.9
Height (cm)	153.2 ± 9.5	166.1 ± 3.2	147.8 ± 4.3
Weight (kg)	53.9 ± 10.3	64.3 ± 6.8	49.4 ± 8.2
BMI (kg/m^2)	22.8 ± 2.9	23.3 ± 2.1	22.6 ± 3.2
AMM (kg)	15.7 ± 3.7	20.5 ± 1.2	13.6 ± 2.0
AFM (kg)	4.8 ± 2.4	4.1 ± 2.2	5.1 ± 2.4
Diagnosis *n* (%)			
Spinal canal stenosis	11 (55%)		
Disc herniation	1 (5%)		
Spinal tumor	2 (10%)		
Knee osteoarthritis	2 (10%)		
Compression fracture	1 (5%)		
Femoral neck fracture	1 (5%)		
Others	2 (10%)		

Values are mean ± standard deviation or *n* (%).
AFM, dual-energy X-ray absorptiometry-derived appendicular fat mass; AMM, dual-energy X-ray absorptiometry-derived appendicular muscle mass; BMI, body mass index.

Table 2 Correlation coefficients between limb muscle mass or fat mass and each optical densities value

	Biceps		Triceps		Flexor carpi radialis	
	OD1	OD2	OD1	OD2	OD1	OD2
Upper limb muscle mass						
Four limbs	0.369	0.350	0.623**	0.534*	0.343	0.324
Upper limb	0.292	0.286	0.572**	0.462*	0.279	0.267
Upper limb fat mass						
Four limbs	−0.570**	−0.551*	−0.483*	−0.494*	−0.827**	−0.821**
Upper limb	−0.423	−0.394	−0.403	−0.411	−0.723**	−0.705**
	Quadriceps		Tibialis anterior		Calf	
	OD1	OD2	OD1	OD2	OD1	OD2
Lower limb muscle mass						
Four limbs	0.332	0.190	0.139	0.118	0.297	0.327
Lower limb	0.383	0.248	0.138	0.125	0.346	0.373
Lower limb fat mass						
Four limbs	−0.348	−0.220	−0.421	−0.388	−0.426	−0.443
Lower limb	−0.333	−0.218	−0.434	−0.401	−0.458*	−0.472*

*$P < 0.05$; **$P < 0.01$. Optical density (OD)1 = 937 nm, OD2 = 947 nm.

Discussion

Recently, Sanada *et al.* reported prediction models for skeletal muscle index using body mass index (BMI) in Japanese adults.[29] The results showed that the R^2 values for the skeletal muscle index were 0.56 in men and 0.45 in women. Similarly, Gallagher *et al.* reported that height and weight accounted for 64% and 67% of the total variance of the appendicular skeletal muscle mass in African-American and Caucasian women, respectively, and 63% and 39% of the total variance in African-American and Caucasian men, respectively.[30] These results showed the difficulty in estimating the AMM accurately using only anthropometric measurements, and the need for an objective method for accurate measurement of body composition.

To address this problem, we investigated whether AMM and AFM could be estimated by a combination of height, weight and NIRS data (OD values). The present results showed that OD1 of the proximal flexor carpi

Table 3 Regression equation for estimating appendicular muscle mass and fat mass

Model	Equation	R^2	SEE
Appendicular muscle mass			
1	$y = 0.23 \times (\text{height}) + 0.13 \times (\text{weight}) - 26.35$	0.81	1.67
2	$y = 0.17 \times (\text{height}) + 0.17 \times (\text{weight}) + 8.45 \times [\text{OD1 [biceps]}) - 28.97$	0.89	1.34
3	$y = 0.13 \times (\text{height}) + 0.18 \times (\text{weight}) + 10.49 \times (\text{OD1 [triceps]}) - 23.19$	0.85	1.55
4	$y = 0.10 \times (\text{height}) + 0.24 \times (\text{weight}) + 7.82 \times (\text{OD1 [flexor carpi radialis]}) - 21.42$	0.89	1.33
5	$y = 0.20 \times (\text{height}) + 0.15 \times (\text{weight}) + 6.12 \times (\text{OD1 [calf]}) - 29.44$	0.85	1.57
Appendicular fat mass			
1	$y = -0.22 \times (\text{height}) + 0.25 \times (\text{weight}) + 25.39$	0.50	1.77
2	$y = -0.17 \times (\text{height}) + 0.21 \times (\text{weight}) - 7.89 \times (\text{OD1 [biceps]}) + 27.84$	0.65	1.52
3	$y = -0.10 \times (\text{height}) + 0.20 \times (\text{weight}) - 12.11 \times (\text{OD1 [triceps]}) + 21.73$	0.61	1.60
4	$y = -0.06 \times (\text{height}) + 0.12 \times (\text{weight}) - 10.01 \times (\text{OD1 [flexor carpi radialis]}) + 19.08$	0.80	1.16
5	$y = -0.19 \times (\text{height}) + 0.23 \times (\text{weight}) - 6.55 \times (\text{OD1 [calf]}) + 28.70$	0.58	1.66

R^2, coefficient of determination; SEE, standard error of the estimate.

radialis, in association with anthropometric data, can provide accurate estimates of both AMM and AFM in older adults, although the NIRS data alone did not reflect muscle mass except at the distal triceps. Furthermore, compared with the estimation equation that included only anthropometric data, the estimation equation that included both anthropometric and NIRS data had a higher coefficient of determination.

In the present study, the NIRS data were obtained at six sites to determine the best location for estimating AMM and AFM. As a result, OD values measured at the distal triceps and proximal flexor carpi radialis showed a good correlation coefficient with limb muscle mass and fat mass, respectively. Yasukawa *et al.* reported that the NIRS data (OD values) measured by BFT-2000 (old model of BFT-3000) had higher correlations with percentage fat at the thinner adipose sites than thicker adipose sites,[31] and similar results were observed by Futrex 5000 in another report.[25] Inconsistent strengths of the association of OD values with total body fat at the various sites might simply be a result of differences in the depth of penetration of the infrared radiation. These results suggested that it might be preferable to carry out measurements at sites where there is little subcutaneous fat, such as the flexor carpi radialis.

There are several reports of NIRS being a valid method to assess the percentage of fat or fat mass. For example, Sawai *et al.* reported that the correlation coefficient between percentage body fat as predicted by the NIRS method and as predicted by the hydrostatic weighing technique was 0.88 ($P < 0.001$, SEE = 3.2).[24] Fuller *et al.* also suggested that NIRS methods using Futrex 5000 have the potential to replace skinfold thickness (SFT) for estimation of body composition.[25] The BFT-3000 used in the present study was developed for Japanese patients, and the principle of measurement was the same as for Futrex 5000. Our findings that NIRS data could accurately reflect fat mass are consistent with a previous study.[25] These results suggest that NIRS is a valid method for the estimation of AFM.

Other reports (by Futrex 5000) showed that NIRS might have little or no advantage over SFT in determining body composition.[32,33] One of the reasons for this controversy is that the degree of obesity differs in each patient. Elia *et al.* concluded that NIRS might underestimate body fat in very obese patients.[32] In the present study, the mean BMI of the patients was 23.3 ± 2.1 kg/m^2 in men and 22.6 ± 3.2 kg/m^2 in women, and there was no patient whose BMI was over 30 kg/m^2. Previous studies of older Japanese patients also reported a BMI ranging from 19.9 to 23.3 kg/m^2.[21,22] These results imply that NIRS data might be less affected by subcutaneous fat in older Japanese patients, and that NIRS is a valid method to assess their percentage fat and fat mass.

In contrast, NIRS data were not correlated significantly with whole and regional muscle mass except in the distal triceps. It is possible that quantitative assessment of skeletal muscle mass might be difficult using only NIRS data, because near infrared light might not reach the deeper muscle layer. However, when bodyweight is divided into fat mass and fat-free mass, skeletal muscle constitutes the largest fraction of appendicular fat-free mass. Previous investigators also proposed several models for predicting skeletal muscle mass with DXA. Lean body mass consists mostly of skeletal muscle. If we obtain an accurate bodyweight and the fat mass, the lean body weight (i.e. skeletal muscle mass) can be calculated automatically. The results in the present study suggest that AMM might be estimated indirectly by using NIRS data and bodyweight.

The present study is limited by the small sample size and orthopedic patients who were mostly women. The estimation equations of AMM and AFM developed in the present study might have high specificity. In addition, we did not confirm the validity of these estimation equations. Thus, further studies are required to check the validity of these equations in other older adults (cross-validity) and longitudinally monitored populations (predictive validity) in the future. Furthermore, these equations will be developed for each sex using larger samples. Finally, to our knowledge, it is unclear whether the OD value (wavelength 937–947 nm) is influenced by blood flow and oxygen saturation. In the previous study, investigators did not mention this point. However, all patients were maintained in a resting position before and during the measurement in the present study. We think that the influence of blood flow and oxygen saturation is not likely to be marked, but this should be considered in a future study.

In conclusion, NIRS data can provide reliable and accurate estimates of AMM and AFM in older adults with the use of anthropometric data (height and weight). The estimation equations of AMM and AFM suggest the possibility that NIRS is a convenient method to assess body composition and to screen sarcopenic (or sarcopenic-obesity) patients. For further adjustment of this equation, it might be expected that sarcopenia or sarcopenic-obesity patients can be screened easily.

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Disclosure statement

The authors have no financial disclosures or other conflicts of interest to report.

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ORIGINAL ARTICLE

Relationship between near-infrared spectroscopy, and subcutaneous fat and muscle thickness measured by ultrasonography in Japanese community-dwelling elderly

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Aim: Near-infrared spectroscopy (NIRS) allows estimation of the percentage of body fat (%BF) regardless of the patient's posture; thus, it is useful for assessment of elderly patients with severe decline of basic activity who cannot hold a standing position. However, the accuracy by which the near-infrared light emitted from NIRS reflects subcutaneous tissue is unknown. The aim of this study was to assess how correctly NIRS reflects the subcutaneous fat and muscle thickness derived from ultrasonography in community-dwelling elderly.

Methods: A total of 93 community-dwelling older adults aged 65 years and older were enrolled in this study (mean 75.8 years, 6.7 SD). Participants were assessed according to optical density (OD) measurements by NIRS, subcutaneous fat and muscle thickness by ultrasonography, and muscle strength. Pearson's correlation coefficients were calculated for each sex. Stepwise multiple regression analysis was used to identify factors that contributed to OD for each sex.

Results: OD measured at the forearm and thigh were significantly correlated with subcutaneous fat thickness. In stepwise multiple regression analyses, subcutaneous fat thickness was found to be a significant determinant of OD in men (forearm $\beta = -0.37$, $P = 0.01$; thigh $\beta = -0.63$, $P < 0.001$) and women (forearm $\beta = -0.50$, $P < 0.001$; thigh: $\beta = -0.52$, $P < 0.001$).

Conclusions: These results suggest that NIRS can appropriately estimate fat-free mass. By adding other variables to OD as the predictive variable, skeletal muscle mass might be estimated in the elderly population. **Geriatr Gerontol Int 2012; ••: ••–••.**

Keywords: near-infrared spectroscopy, older adults, sarcopenia, subcutaneous fat thickness, subcutaneous muscle thickness.

Introduction

Sarcopenia is the loss of muscle mass and function related to aging[1–5]. A study reported that older sarcopenic patients are twice as likely to contract infection during a hospital stay compared with older patients with a normal muscle mass.[6] This suggests that sarcopenic individuals might have decreased immunity, which might provide a mechanistic link between sarcopenia and mortality risk. In fact, a low corrected arm muscle area independently predicts long-term mortality in community-dwelling older adults.[7] According to the New Mexico Elder Health Survey, the prevalence of sarcopenia increased from 13% to 24% in persons aged less than 70 years to >50% in persons aged more than 80 years.[8] To achieve successful aging, it is important to preserve a certain amount of muscle mass.

Some researchers recently showed that sarcopenic obese persons are at a particularly high risk for functional impairment and physical disability.[8–11] A previous report suggested that approximately 15% of sarcopenic persons are also obese.[8] Thus, not only muscle mass, but also fat mass, should be accurately assessed in older adults.

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Protein energy malnutrition (PEM) is related to various risk factors (pressure sores, pneumonia, postoperative complications, anemia, loss of bone mineral, femoral neck fracture, cognitive impairment, low activities of daily living, low quality of life and sarcopenia).[12] Furthermore, PEM independently predicts long-term mortality in hospitalized older adults.[13] These individuals should have increased protein consumption, because energy uptake is insufficient in PEM; thus, the body protein (particularly in skeletal muscle) decreases. Therefore, sarcopenic patients might also have PEM. PEM has been reported to be prevalent in hospitalized older adults and nursing home residents,[14–16] whose physical functions often decrease severely. Therefore, body composition should be evaluated in patients with severe decline in physical function.

The most highly accurate method for measuring limb composition is whole-body dual-energy X-ray absorptiometry (DXA).[17] DXA can simultaneously measure body fat mass and bone mineral density. However, whole-body DXA is costly and time intensive. This scan also involves some exposure to radiation. Therefore, the use of bioelectrical impedance analysis (BIA) instruments has gained increasing attention both in the clinic and among the general population. However, few reports have been published about the measurement of body composition in lean elderly patients with severe decline in physical function.

BIA is a non-invasive, portable, quick and inexpensive method for measuring body composition.[18] It is the most common method for measuring body composition in Japan. However, many BIA instruments require patients to maintain a standing position for the measurement. Therefore, BIA instruments are often not used for elderly patients with severe decline in basic activity who cannot hold a standing position. Another method that might have potential for use in older adults is near-infrared spectroscopy (NIRS). NIRS is also a non-invasive, portable, simple and rapid method for assessing the percentage of body fat (%BF). The NIRS instrument allows estimating a patient's %BF simply by placing the tip of the probe against the center of the front side of the arm, regardless of the patient's posture.

Some reports showed that NIRS has a high reliability and accuracy in assessing %BF.[19–22] However, there has been no report on how correctly the near-infrared light emitted from NIRS reflects the subcutaneous tissue, particularly the muscle, at the irradiation point. Therefore, whether NIRS accurately estimates fat and muscle mass is unknown. Regional fat and muscle thickness can be accurately quantified with ultrasonography.[23,24] A previous study reported that the muscle cross-sectional area measured by ultrasonography is related to muscle strength.[25] If NIRS can reflect regional muscle mass, then there might be a relationship between the variable derived from NIRS and muscle strength.

The aim of the present study was to assess how correctly NIRS reflects the subcutaneous fat and muscle thickness derived from ultrasonography in community-dwelling older adults.

Methods

Participants

The participants were recruited from two volunteer databases ($n = 1543$), which included elderly individuals aged 65 years and older who were selected either by random sampling, or from those who attended a health check in Obu City near Nagoya in Japan. Among the 165 participants who responded to the eligibility assessments, 125 completed the strength, NIRS and ultrasound measurements. The inclusion criteria for the present study required that the participants be aged 65 years or older, living independently in the community, Japanese speaking, and with sufficient hearing and visual acuity to participate in the examinations. The exclusion criteria included a history of major psychiatric illness (e.g. schizophrenia or bipolar disorder), other serious neurological or musculoskeletal diagnoses, and clinical depression (Geriatric Depression Scale [GDS] score ≥10). A total of 93 out of 125 participants satisfied the inclusion criteria and were analyzed in the present study.

The present study was approved by the ethics committee of the National Center for Geriatrics and Gerontology. All participants provided written informed consent.

Near-infrared spectroscopy

The NIRS measurements used the Fitness Analyzer BFT-3000 (Kett Science, Tokyo, Japan), the Japanese version of Futrex 5000 (Futrex, Hagerstown, MD, USA), which can estimate body composition.[20,26] This device measures optical densities (OD) at two wavelengths (OD1 = 937 nm, OD2 = 947 nm). The NIRS instrument was tested immediately before obtaining measurements for each patient by using the optical standard provided with the instrument, which is situated in a flexible light shield to ensure its consistent performance throughout the study.

OD values were obtained at two sites: the forearm (flexor carpi radialis) and thigh (quadriceps). Participants were required to maintain a seated position, with their hands dropped to their sides. A single trained physical therapist carried out the NIRS measurements, which were completed in a few minutes.

Ultrasonography

The Miru Cube ultrasound scanning system (Global Healt, Kanagawa, Japan) with a 6-MHz linear array transducer, a portable instrument developed for measuring subcutaneous fat and muscle thickness outside the clinic,[27] was used for measuring the thicknesses of two kinds of subcutaneous soft tissue: fat and muscle. Measurements were taken in longitudinal directions. Participants were required to maintain a seated position, with their hands dropped to their sides. Scans were taken at the same sites (forearm and thigh) as those in NIRS measurements. A single trained physical therapist carried out the scans, which were completed in a few minutes.

The images were transferred to a computer for quantification. Subcutaneous fat and muscle thicknesses were automatically measured using software for exclusive use.

Muscle strength

Grip strength and isometric knee-extension strength were evaluated. The grip strength was measured using a Smedley-type digital hand dynamometer (model TKK5401; Takei Scientific Instruments, Niigata, Japan). The participants were instructed to apply as much hand-grip pressure as possible with their dominant hand in a standing position.

Isometric knee-extension strength was tested on a dynamometer (model MDKKS; Molten, Hiroshima, Japan). For the knee extension test, the right leg was used unless contraindicated by pain or a history of joint replacement. Knee extension was measured while the participant was sitting (knee joint angle of 90°) on a chair by placing a strap around the leg just proximal to the ankle joint. In two experimental trials, the participant pulled against the strap assembly with maximal force; the greatest force was recorded. Isometric knee-extension torque was normalized against the moment arm and body mass (N m/kg) in the data analysis.

Statistical analysis

Student's *t*-tests were used to compare the demographic data, OD, subcutaneous soft tissue thicknesses, and muscle strengths between men and women.

Pearson's correlation coefficients were calculated for each sex to assess simple relationships between OD and subcutaneous soft tissue thicknesses or strengths. Stepwise multiple regression analysis was used to identify factors that contributed to OD for each sex and each measurement site (forearm or thigh). Because there were high correlation coefficients between OD1 and OD2 ($r > 0.969$) and all correlation coefficients were higher at OD1 than at OD2, OD1 was used as the representative value. For the analysis of variables measured in the forearm, OD1 in the forearm was considered the dependent variable, and subcutaneous soft tissue thicknesses in the forearm and grip strength were considered independent variables. For the analysis of variables measured in the thigh, OD1 in the thigh was considered the dependent variable, and subcutaneous soft tissue thicknesses in the thigh and knee-extension strength were considered independent variables.

We considered a value of 5% to be significant. We analyzed the data using IBM SPSS Statistics version 19 for Windows (SPSS, Chicago, IL, USA).

Results

The mean (SD) age of all participants was 75.8 years (6.7). Table 1 summarizes the characteristics and the sex differences of the participants.

The correlation coefficients between subcutaneous soft tissue thicknesses or strengths and each OD value are listed in Table 2. In both men and women, subcutaneous fat thickness in the forearm was significantly correlated with OD in the forearm or the thigh (both OD1 and OD2). In men, subcutaneous fat thickness in the thigh was significantly correlated with OD in the forearm or the thigh (both OD1 and OD2). In women, subcutaneous fat thickness in the thigh was significantly correlated with OD in the thigh (both OD1 and OD2). In men, knee-extension strength was significantly correlated with OD in the forearm (both OD1 and OD2). In the correlation analysis between subcutaneous fat thickness and OD value, all correlation coefficients were higher at OD1 than at OD2 (Figure 1).

In stepwise multiple regression analyses, subcutaneous fat thickness was found to be a significant determinant of OD1 in men (forearm $\beta = -0.37$, $P = 0.01$; thigh $\beta = -0.63$, $P < 0.001$) and women (forearm $\beta = -0.50$, $P < 0.001$; thigh $\beta = -0.52$, $P < 0.001$; Table 3).

Discussion

The power with which light enters the body is called penetrability. The penetrability of light is proportional to the wavelength. Electromagnetic waves with a short wavelength, such as visible light or near-infrared light, have low penetrability and can only warm the surface of the skin. The NIRS instrument used in the present study also measures the amount of subcutaneous soft tissue by means of such near-infrared light; thus, the light might not reach a deep subcutaneous point. A previous study reported that the deviation in optical path length in NIRS becomes large when there is a big difference in the skinfold thickness among participants.[28]

A previous study showed that the distances from the skin surface to muscle measured using an ultrasonography image scanner were 1.0–2.5 cm in participants whose body mass index was 20–24.[29] The NIRS instrument has been used to measure subcutaneous soft

Table 1 Participants' demographic information

Variables	Total $n = 93$	Men $n = 50$	Women $n = 43$	P-value
Age (years)	75.8 (6.7)	76.0 (6.5)	75.7 (6.9)	0.84
Height (cm)	154.6 (8.4)	159.9 (5.6)	148.4 (6.7)	<0.001
Weight (kg)	55.9 (8.7)	58.6 (7.8)	52.7 (8.6)	<0.001
BMI (kg/m^2)	23.3 (2.8)	22.9 (2.6)	23.8 (3.0)	0.10
OD (log1/I)				
Forearm				
OD1	1.090 (0.118)	1.138 (0.107)	1.036 (0.104)	<0.001
OD2	1.122 (0.108)	1.163 (0.099)	1.074 (0.096)	<0.001
Thigh				
OD1	1.036 (0.099)	1.059 (0.102)	1.010 (0.087)	0.01
OD2	1.100 (0.087)	1.114 (0.091)	1.084 (0.079)	0.10
Subcutaneous thicknesses (mm)				
Forearm				
Fat	4.7 (1.7)	4.4 (1.4)	5.0 (1.9)	0.09
Muscle	30.2 (3.0)	31.6 (2.4)	28.5 (2.7)	<0.001
Thigh				
Fat	6.6 (2.7)	5.8 (1.5)	7.5 (3.3)	<0.01
Muscle	18.9 (5.1)	18.7 (4.3)	19.0 (5.9)	0.75
Grip strength (kg)	25.6 (8.1)	30.8 (5.9)	19.6 (5.9)	<0.001
Knee-extension strength (N m/kg)	1.007 (0.381)	1.145 (0.347)	0.847 (0.356)	<0.001

Values are mean (SD). BMI, body mass index; OD, optical density; OD1, optical density at 937 nm; OD2, optical density at 947 nm.

Table 2 Correlation coefficients between subcutaneous thicknesses or strengths and each optical density value

	Forearm		Thigh	
	OD1	OD2	OD1	OD2
Men ($n = 50$)				
Subcutaneous thickness				
Fat in the forearm (mm)	−0.37**	−0.30*	−0.32*	−0.28*
Muscle in the forearm (mm)	−0.02	0.03	−0.01	0.04
Fat in the thigh (mm)	−0.38**	−0.35*	−0.63***	−0.58***
Muscle in the thigh (mm)	0.00	0.07	−0.05	−0.03
Grip strength (kg)	0.24	0.23	0.13	0.14
Knee-extension strength (N m/kg)	0.33*	0.35*	0.08	0.12
Women ($n = 43$)				
Subcutaneous thickness				
Fat in the forearm (mm)	−0.50***	−0.44**	−0.48**	−0.48**
Muscle in the forearm (mm)	−0.10	−0.08	−0.12	−0.09
Fat in the thigh (mm)	−0.28	−0.26	−0.51***	−0.45**
Muscle in the thigh (mm)	−0.25	−0.23	−0.12	−0.03
Grip strength (kg)	0.09	0.09	0.10	0.14
Knee-extension strength (N m/kg)	0.13	0.15	0.01	0.01

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. OD, optical density; OD1, optical density at 937 nm, OD2, optical density at 947 nm.

tissue at a depth of 1.0–2.5 cm from the skin surface.[30] In the participants of the present study, the mean values of subcutaneous fat thickness were 7.2 mm (forearm of men), 8.8 mm (thigh of men), 8.8 mm (forearm of women), and 16.1 mm (thigh of women); the mean values of subcutaneous muscle thickness were 31.6 mm (forearm of men), 18.7 mm (thigh of men), 28.5 mm (forearm of women) and 19.0 mm (thigh of women).

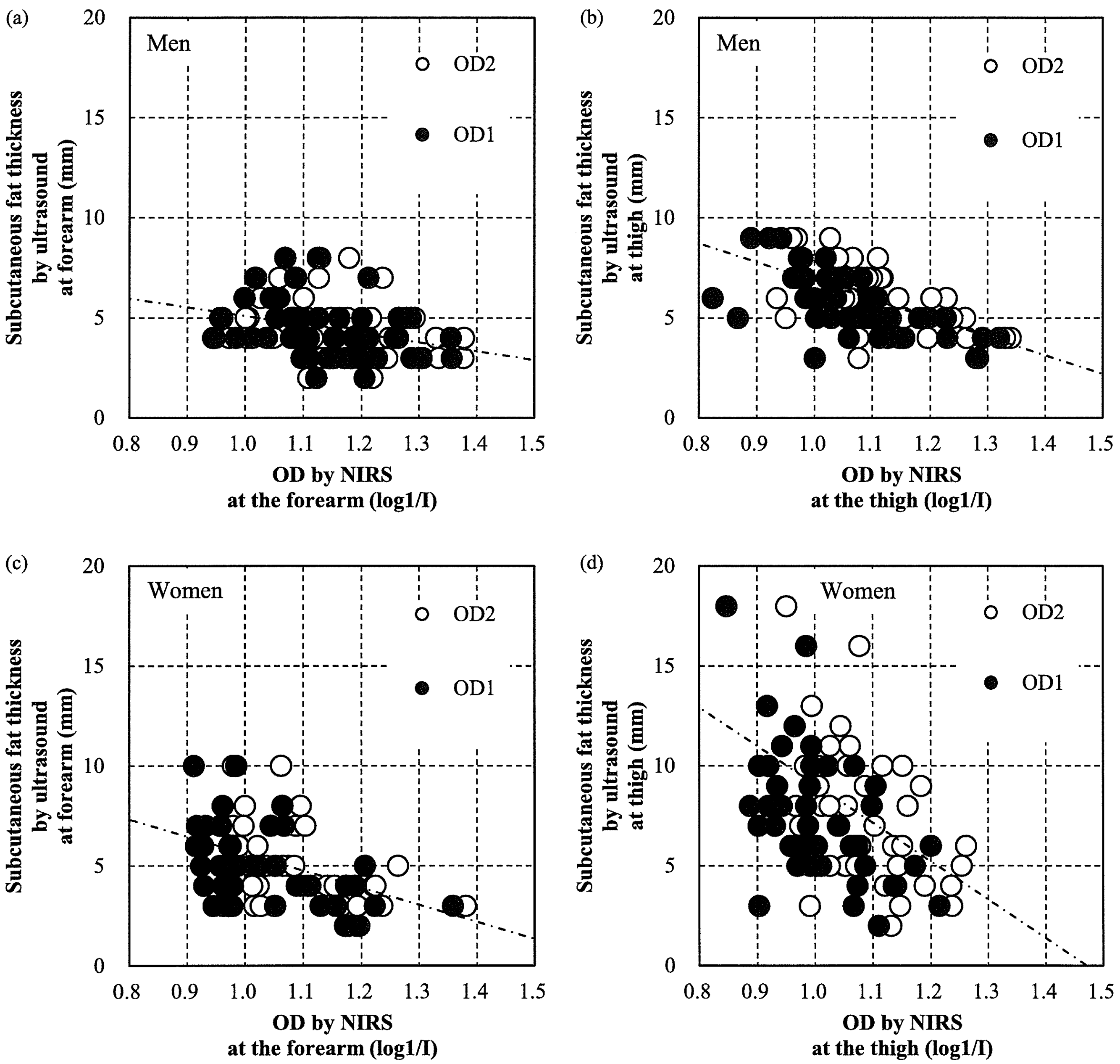

Figure 1 Scatter plot graphs showing the correlation between the subcutaneous fat thickness measured by ultrasound and the optical density (OD) from near-infrared spectroscopy (NIRS). (a,b) Data for men. (c,d) Data for women. Straight lines represent the regression line of OD at 937 nm (OD1), and broken lines represent the regression line of OD at 947 nm (OD2).

These results suggest that the near-infrared lights used in the present study did not reach the deepest point of the subcutaneous muscle layer of the participants. They also suggest that there was no significant correlation between OD and subcutaneous muscle thickness, although there were significant correlations between OD and subcutaneous fat thickness. In the stepwise multiple regression analysis, only subcutaneous fat thickness was included as a significant independent variable relevant to the OD value, and subcutaneous muscle thickness was excluded. Therefore, the estimation of muscle mass by NIRS is interpreted as lacking construct validity. However, this implies the opposite interpretation that the estimation of fat mass by NIRS has sufficient construct validity.

A two-component model dividing the human body into fat mass and fat-free mass is used when considering body composition at the molecular level.[31] This two-component model was the foundation of many methods for estimating body composition developed in the past. In this model, the construct validities for estimation of the fat mass and the fat-free mass are equally sufficient.

Table 3 Determinants of optical density at 937 nm in men and women

Independent variable	Men ($n = 50$)		Women ($n = 43$)	
	β	*P*-value	β	*P*-value
Forearm				
Entered				
Thickness of subcutaneous fat	−0.37	0.01	−0.50	<0.001
Removed				
Age	−1.33	0.19	−1.00	0.32
Thickness of subcutaneous muscle	−0.53	0.60	0.46	0.64
Grip strength	1.65	0.11	1.11	0.27
Thigh				
Entered				
Thickness of subcutaneous fat	−0.63	<0.001	−0.52	<0.001
Removed				
Age	−1.12	0.27	−0.62	0.54
Thickness of subcutaneous muscle	−0.02	0.99	−0.24	0.81
Knee-extension strength	0.79	0.43	0.33	0.74

Standardized beta values represent the correlation between optical density at 937 nm and each independent variable. OD, optical density; OD1, optical density at 937 nm.

Therefore, the results of the present study suggest that estimation of fat-free mass by using OD from NIRS has sufficient construct validity. When body composition is considered at the tissue level, the skeletal muscle is known to make up most of the fat-free mass.[31]

However, no significant correlation was found between OD and muscle strength in the present study. This suggests that the variable derived from NIRS is not the only index for estimating fat-free mass. A previous study has shown that there is a relationship between lean body mass and strength.[32] Furthermore, one report[33] suggested that the coefficient of determination became highest when the factors of maximum grip strength and physical performance were added as independent variables in the multiple linear regression model wherein lean mass was the dependent variable (adjusted for age, height, fat mass and activity) A high accuracy might be achieved if the muscle mass is determined by a multivariable estimation that includes OD plus physique indexes (such as height and fat mass), age and activity as independent variables.

To appropriately evaluate sarcopenia, it is ideal to directly measure the whole body skeletal muscle mass. However, it is very difficult to directly measure the body composition of a living human being; thus, an estimation is usually used. Because sarcopenia is related to critical risk factors, body composition needs to be estimated with high accuracy. If the body compositions of a population comprising various body forms are estimated from a single variable, great differences between the true values and the predicted values will be inevitable. Therefore, two or more variables should be used for estimation of body composition. For estimating body composition by using several variables, NIRS, which can appropriately estimate fat-free mass, might be an effective tool.

The present study was limited by all participants having a normal physique. In addition, we did not confirm the predictive validity, because the design of the present study was cross-sectional. Thus, the validity of the method should be confirmed by using longitudinally monitored populations including both thin and obese participants.

In conclusion, the OD value obtained by NIRS was strongly related to subcutaneous fat thickness. This result suggests that NIRS can appropriately estimate fat-free mass. If other variables are added to the OD as the predictive variable, skeletal muscle mass might be estimated with high accuracy in the elderly population.

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ORIGINAL ARTICLE

Relationship between dual-task performance and neurocognitive measures in older adults with mild cognitive impairment

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Aim: The aim of this study was to examine the relationship between dual-task performance and neurocognitive measures in community-dwelling older people with mild cognitive impairment (MCI).

Methods: A total of 98 subjects (mean age 74.8 years, 52.0% female) participated in the study. We compared 36 participants with amnestic MCI (aMCI) with 62 participants with non-amnestic MCI (non-aMCI) on dual-task performance as measured by reaction time responses. The relationships between dual-task performance and multiple domains of neurocognitive functions, including general cognitive function, visual memory, working memory, executive function and processing speed, were examined.

Results: Although there were no statistically significant group differences in simple reaction times ($P = 0.734$), the aMCI group showed significantly slower dual-task reaction times than the non-aMCI group ($P = 0.012$). Using multiple regression analysis, we found that there was a significant relationship between executive function and dual-task reaction times ($\beta = 0.298$, $P = 0.006$).

Conclusion: These results showed that aMCI subjects showed a specific deficit in dual-task performance compared with non-aMCI subjects, and poor dual-task performance was associated with declines in executive function in older people with MCI. Future longitudinal and interventional studies should investigate the use of dual-task testing with varying levels of cognitive demand in older adults at risk of dementia. **Geriatr Gerontol Int 2012; ••: ••–••.**

Keywords: dual-task, executive functioning, mild cognitive impairment, reaction time.

Introduction

Alzheimer's disease (AD) is the most common form of dementia, and mild cognitive impairment (MCI) is associated with an elevated risk of developing AD.[1] Along with amnesia, a decline of attentional control of executive function is one of the earliest symptoms of dementia.[2]

Dual-task performance can be measured while a person carried out two concurrent tasks, and reflects divided attention, considered an important executive function.[3,4] Several studies have reported an association between AD and impairments in dual task performance, indicating a specific deficit of dual-task functioning in the disease.[5–8] Additionally, MCI patients might also show specific deficits in dual-task performance, as impaired executive function in MCI plays a crucial role in the conversion to AD.[9,10] In contrast, a previous study reported that dual-task performance has been found to have lower sensitivity in discriminating between controls, MCI patients and AD patients, whereas dual-task performance during walking in MCI patients resembled that of AD patients but not control subjects.[11] Thus, it is currently unclear whether poor dual-task performance is related to decline in neurocognitive functions among older adults with MCI.

Sheridan *et al.* suggested that dual-task-related performance changes were correlated with executive and neuropsychological function in patients with AD.[12] In MCI patients, neuropsychological functioning of working memory was associated with impaired dual-task performance.[13] However, few studies of dual-task performance and multiple domains of neurocognitive

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functioning have focused on older adults at risk of developing dementia, especially those with MCI.[14] If dual-task performance is closely related to specific domains of neurocognitive function, it might provide an objective measure of the effectiveness of new intervention strategies in older adults with cognitive decline.

In the present study, the dual-task reaction time (RT) paradigm[15–17] was used to assess attentional demands, because we considered that measurements of RT were simple and easy to understand in older adults (including MCI patients), even in a clinical setting. It is currently unclear whether neuropsychological measures in MCI patients are correlated with dual-task performance. The current study sought to assess attention-related performance using RT in a dual-task, and to examine the relationships between dual-task performance and multiple domains of neurocognitive functions, including general cognitive function, visual memory, working memory, executive function and processing speed in community-dwelling older adults with MCI. Furthermore, we compared amnestic MCI (aMCI) and non-amnestic MCI (non-aMCI) participants, because aMCI is likely to progress to AD.[18,19]

Methods

Participants

Participants were recruited from two volunteer databases ($n = 1543$), which included elderly individuals aged 65 years and older, selected either by random sampling or when they attended a health check in Obu, Japan. For inclusion, all participants were required to meet the definition of MCI using the Petersen criteria.[20] A total of 126 older adults that had a clinical dementia rating (CDR) of 0.5 or a memory complaint were assessed for 2 days by neuropsychological tests, physical performance tests and face-to-face interviews. Other criteria for inclusion into the present study required that the participant was aged 65 years or older, living independently in the community (i.e. no impairment of activities of daily living) and Japanese speaking, with sufficient hearing and visual acuity to participate in the examinations, and general cognitive functioning (Mini-Mental State Examination [MMSE][21] scores between 24 and 30). Exclusion criteria included a history of major psychiatric illness, other serious neurological or musculoskeletal diagnoses, and clinical depression. Finally, 98 participants with MCI (mean age 74.8 years, male/female 47/51, mean education 10.7 years) satisfied the inclusion criteria, and their data were analyzed in the present study. Participants were classified into aMCI and non-aMCI groups. Of the 98 participants, 36 were included in the aMCI group, because they showed memory impairments that were objectively established through education-adjusted scores on the Wechsler memory Scale – Revised (WMS-R) Logical Memory II.[22,23] The non-aMCI participants ($n = 62$) did not show objective memory impairment as measured by education-adjusted scores on the WMS-R Logical Memory II scale. However, they had a CDR of 0.5 or a memory complaint, and they met the threshold for an MCI diagnosis using the Petersen criteria (not normal for age, not demented, cognitive decline and essentially normal functional activities).[20] The present study was approved by the ethics committee of the National Center for Geriatrics and Gerontology. All participants provided written informed consent.

Dual-task performance measures

We measured RT under two conditions of cognitive demand of attentional resources: a low demand (simple-task) condition and a high demand (dual-task) condition. Simple RT was measured by pushing a handheld button as quickly as possible in response to a visual stimulus (a bright red light). In addition, each participant's RT were measured in the dual-task condition while carrying out a concurrent cognitive task. This was defined as dual-task performance. First, participants' simple RT were measured in a quiet standing position. RT were defined as the temporal interval between the presentation of a visual stimulus and the onset of a pushing response. During simple RT measurement, participants were asked to push a handheld button as quickly as possible after the presentation of a red light stimulus composed of seven small lights (each with a diameter of 5 mm). The experimenter confirmed that participants stood quietly, then issued the verbal command, "ready", as a verbal starting signal before RT measurement. The visual starting signal and verbal command preceded each trial. RT responses were measured by a time counter (PTS-010; DKH, Itabashi, Japan) and displayed in milliseconds (ms). In the dual-task condition, participants were asked to count backward to 1, starting from 100, 90, 80, 70, 60, 50, 40, 30 and 20 (selected randomly). They were asked to carry out RT responses during the dual-task with cognitive demands. RT were measured three times for each participant in both conditions. In both task conditions, participants practiced once before data collection commenced. In each task condition, the average RT over three trials was submitted to statistical analysis.

Neurocognitive assessments

Participants underwent comprehensive neurocognitive evaluation, including measures of general cognitive function, visual memory, working memory and executive function. The neurocognitive assessment had a standardized format and was administered by licensed and well-trained clinical speech therapists.

General cognitive function was examined using the Japanese version of MMSE.[24] The Rey-Osterrieth Complex Figure Test (ROCF)[25] and the verbal digit span test[26] were used to assess visual and working memory, respectively. The ROCF is a widely-used instrument for assessing visual memory. The participant was requested to copy the ROCF figure and reproduce it after a 30-min delay. We assessed working memory using the verbal digit span test.[26] The digit span test includes both forwards and backwards conditions, in which a participant is given a number sequence and is asked either to repeat it as it was given or to repeat it in the reverse order. The test includes two sequences of each length and testing ceases when the participant fails to recollect any two with the same length. The score recorded, ranging from 0 to 14, is the number of successful sequences. The difference between the verbal digits forward test score and the verbal digits backward test score was used as an index of the central executive component of working memory. Smaller difference scores indicate better working memory.

We used the Digit Symbol-Coding subtest of the Wechsler Adult Intelligence Scale III (WAIS-III)[26] and Trail Making Test (TMT)[27] to assess processing speed and executive function. In the Digit Symbol-Coding test, participants copy symbols that are paired with numbers. Using the key provided at the top of the exercise form, the participant draws the symbol under the corresponding number. The score is the number of correct symbols drawn within 120 s, and a maximum score of 133. Higher scores indicate better processing speed. The TMT consists of two parts, A and B. Part A requires the participant to draw a line as rapidly as possible joining consecutive numbers (1–25). In Part B, the participant must draw a line alternately between consecutive numbers and letters (1-A-2-B-12-L). In the Japanese version of the TMT-B, letters from the Roman alphabet are exchanged for Kana characters. We recorded the amount of time (in seconds) it took to complete each task. We calculated the difference between Part B and Part A completion time (delta TMT). Smaller difference scores indicate better executive function.

Statistical analyses

Student's t-tests or χ^2-tests were used to compare the demographic, reaction time responses, and neurocognitive functions between the aMCI and non-aMCI groups. Pearson's correlation coefficients were used to quantify the bivariate associations between RT during single-task and dual-task conditions, and neurocognitive measures. While controlling for the possible confounding influences of age-related changes and length of education in reaction times during simple-task and dual-task conditions, standardized β-values were calculated using linear regression analysis to assess the relationships between the variables. Multiple linear regression models were constructed to determine the independent association of neurocognitive measures using simple RT and dual-task RT. We calculated the R^2- and standardized β-values for each regression model. The statistical analyses were carried out using SPSS for Windows version 17.0 (SPSS, Chicago, IL, USA). The level of statistical significance was set at 0.05 for all analyses.

Results

Table 1 summarizes the characteristics of the participants in the aMCI and non-aMCI groups. There were no statistically significant between-group differences in age, sex, hypertension, diabetes mellitus, medication and clinical depression status. The participants in the aMCI group had significantly lower ROCF scores compared with the non-aMCI group ($P = 0.008$). There were no statistically significant between-group differences in other neurocognitive measurements. Although there were no statistically significant group differences in simple RT ($P = 0.734$), the participants in the aMCI group had significantly longer dual-task RT than the participants in the non-aMCI group ($P = 0.012$).

Table 2 shows the correlation coefficients of the relationships between RT during the single-task and dual-task conditions and neurocognitive measures, and shows the standardized β-values derived from the linear regression analyses after controlling for age and education. Simple RT were significantly correlated with Digit Symbol-Coding test scores ($r = -0.282$, $P = 0.027$) in the participants in the non-aMCI group, but this was not statistically significant after controlling for age and education ($\beta = -0.111$, $P = 0.476$). Dual-task RT were significantly correlated with Digit Symbol-Coding scores in the participants in both groups (non-aMCI $r = -0.386$, $P < 0.001$; aMCI $r = -0.402$, $P = 0.015$). These relationships were no longer significant in the participants in the aMCI group after controlling for age and education ($\beta = -0.163$, $P = 0.374$), but remained significant in the participants in the non-aMCI group ($\beta = -0.363$, $P = 0.021$). Additionally, dual-task RT were associated with ROCF scores ($r = -0.317$, $P = 0.012$) and delta TMT (times of TMT-B minus TMT-A; $r = -0.429$, $P = 0.001$) in the participants in the non-aMCI group, and these relationships were still significant after controlling for age and education (ROCF $\beta = -0.275$, $P = 0.035$, delta TMT $\beta = 0.380$, $P = 0.003$).

Table 3 shows the results of the multiple regression models that were used to independently determine the associations between neurocognitive functions and simple RT and dual-task RT. The group (aMCI), age, education, MMSE, ROCF, delta TMT, scores of the Digit Span Forward–Backward and Digit Symbol-Coding score parameters accounted for 13.0% of the variance in simple RT. Using multiple regression