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ORIGINAL ARTICLE

Differences in lower limb muscle strength and balance ability between sarcopenia stages depend on sex in community-dwelling older adults

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Abstract

Aim This study aimed to compare motor function between sarcopenia stages with respect to sex in community-dwelling older adults.

Methods The participants, comprising 2107 community-dwelling older adults (738 men and 1369 women), were classified into 4 groups and the groups were operationally defined—normal, low muscle mass, low physical function, and sarcopenia groups. Lower limb muscle strength and balance ability were assessed for evaluating motor function. To compare motor function between sarcopenia stages, an analysis of covariance adjusted for age and body mass index was performed.

Results Lower limb muscle strengths were significantly lower not only in the sarcopenia group but also in the low muscle mass and low physical function groups than that in the normal group in both men and women. Low hip abductor muscle strength was observed in the low physical function group compared to the low muscle mass group in women, but not in men. Timed Up and Go test results in the sarcopenia and low function groups was lower than in the normal and low muscle mass groups for men and women. One-leg standing in the low physical function group was lower than that in the normal group, only for women.

Conclusions Reduced motor function was observed not only in older people with sarcopenia but also in older people with only low muscle mass or low physical function, and the decline in lower limb muscle strength and balance ability in the low function group were greater in older women than in older men.

Keywords Sarcopenia · AWGS2019 · Motor function · Sex difference

Introduction

Sarcopenia, which is defined as age-related skeletal muscle atrophy and low muscle strength and/or low physical performance, has been associated with the risk of falls, long-term care, and mortality in older adults [1]. Some large cohort epidemiological studies reported that the incidence of sarcopenia was approximately 7.3–12.0% in Asia [2, 3], based on a diagnostic algorithm for sarcopenia of the Asian Working Group for Sarcopenia (AWGS) in 2014.

In 2019, the AWGS published an updated consensus that revised the classification and diagnostic algorithm for sarcopenia (AWGS 2019) [3]. According to the updated AWGS 2019 criteria, the 5-time chair stand test and Short Physical Performance Battery (SPPB) were added as indicators of physical performance in addition to the usual gait speed. In addition, the cutoff values for low grip strength and slow gait speed were raised. Tabara et al. [4] reported that the number of participants diagnosed with sarcopenia based on AWGS 2019 criteria increased by 2.3% compared to that by AWGS 2014 criteria, and that sarcopenia and severe sarcopenia diagnosed according to the AWGS 2019 criteria were associated with carotid artery hypertrophy. This suggests the importance

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of earlier interventions for older adults who have been overlooked by traditional diagnostic criteria.

In addition to sarcopenia, primary health care and health promotion among community-dwelling older adults who are at greater risk for developing sarcopenia in the near future owing to low muscle mass or low physical function are important. Previous studies reported that older adults in the "pre-sarcopenia" stage, defined as older adults with low muscle mass but no weakness or poor physical function by the European Working Group on Sarcopenia (EWGSOP), have the same risk of decreased psychological function [5] and low bone mineral density [6] as those in the sarcopenia stage. In contrast, many older adults do not have muscle mass loss but have muscle weakness, since an age-related decline in muscle strength is greater than that in muscle mass. Tanimoto et al. [7] reported that the risk of falls in older adults was associated with the group with low muscle strength and physical performance, but not in the group with low muscle mass. In addition, mortality has been reported to be associated with the group with muscle weakness, but not with the group with low muscle mass [8]. Therefore, to promote healthy aging, it is important to gain a better understanding of the motor functional characteristics according to sarcopenia stage.

Motor function, especially lower limb muscle strength or balance ability, is the most important factor associated with independence in walking, or the risk of falls in older adults [9]. Generally, the measurement of knee extensor muscle strength is used as the lower limb muscle strength. However, the assessment and intervention of hip muscle strength is also important for older adults, since the hip abductor and flexor muscle strength are also strongly related to walking ability [10]. In addition, differences in lower limb muscle strength, and those in the association between lower limb muscle strength and walking ability are related to sex [11]. Therefore, it is predicted that the characteristics of motor function according to the sarcopenia stage may also differ between men and women. However, there are no studies comparing the characteristics of motor functions such as lower limb muscle strength and balance ability by sarcopenia stage and even by sex. Identifying these relationships will help designing individualized and sex-specific exercise programs for each sarcopenia stage.

The purpose of this study was to compare motor function between sarcopenia stages with respect to sex, particularly in older adults who are at greater risk of developing sarcopenia in the near future owing to low muscle mass or low physical function. This study hypothesizes that the characteristics of loss of motor function differ according to sarcopenia stage and sex.

Methods

Study design and participants

This study was conducted as a part of the "Nagahama Prospective Cohort for Comprehensive Human Science (the Nagahama Study)", and the dataset was obtained during the second investigation of the Nagahama Study. Participants in the Nagahama Study were recruited from community residents aged 30–80 years with no serious health problems in Nagahama city, Shiga prefecture, between 2008 and 2010, through newspapers and magazine advertisements. A total of 9,850 individuals aged 35–81 years were enrolled in the second investigation of the Nagahama Study. We provided additional explanations regarding the optional physical assessment to 5,018 participants aged 60 years or older. The inclusion criteria were older adults aged ≥ 60 years with the ability to walk at least 12 m without assistive devices. Among the 5018 older adults aged ≥ 60 years who participated in the second investigation, 2121 participants who voluntarily participated in an optional physical performance test conducted between 2012 and 2017 were included in the study. The exclusion criteria were as follows: (1) incomplete measurements owing to physical dysfunction such as severe musculoskeletal and acute neurological impairments and complaints of pain and fatigue; (2) communication problems owing to cognitive impairments that affected measurements; or (3) lack of any one of the physical function data. We excluded participants with incomplete measurements owing to severe musculoskeletal impairments ($n = 4$), complaints of pain and fatigue ($n = 3$), or lack of data ($n = 7$), resulting in a total of 2107 participants being included in the final analysis (Fig. 1). The sample size was computed using G*power assuming a significance level of $\alpha = 0.05$, β (1 − power) = 0.80, and a medium effect size ($f = 0.38$) based on a previous study [12, 13]. The sample size needed to identify the main parameters was 20 participants in each group.

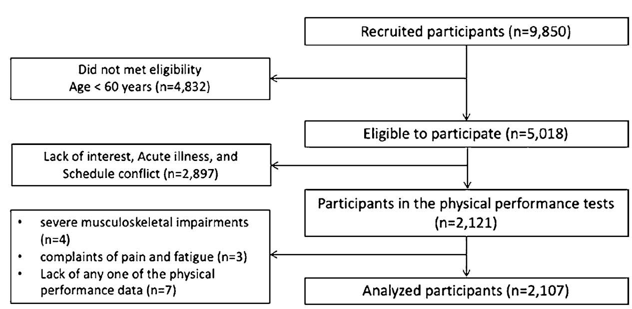

Fig. 1 Participants in the second investigation

The study protocol was approved by the ethics committee of the Kyoto University Graduate School of Medicine and by the Nagahama Municipal Review Board. The content of the study was explained to the participants, and written informed consent was obtained from them.

Skeletal muscle mass measurement

Skeletal muscle mass was measured using bioelectrical impedance analysis (BIA) using a multi-frequency electrical impedance meter (Body 430, Biospace Japan, Tokyo, Japan). Previous studies have shown that the measurements of BIA are accurate in evaluating skeletal muscle mass, similar to dual X-ray absorptiometry (DXA), magnetic resonance imaging (MRI), and computed tomography (CT), which is the gold standard method [1, 2, 14]. The skeletal muscle index (SMI) was calculated as an index of extremity skeletal muscle mass by dividing the value of extremity skeletal muscle mass measured by BIA by the square of body height. Low skeletal muscle mass was defined as SMI less than 7.0 kg/m^2 in men and 5.7 kg/m^2 in women, based on the diagnostic criteria of AWGS 2019.

Grip strength and physical performance measurement

For the diagnosing sarcopenia, grip strength, usual gait speed, 5-time chair stand test, and SPPB were measured.

Grip strength was measured twice on both sides using a grip dynamometer, and the average values were calculated for each of the left or right side. The larger average value of the left or right sides was used in the analysis.

The usual gait speed was measured using a wireless phototube (Brower Timing Systems, Co., Ltd., UT, USA). The phototube was set at 4 m and 10 m from the starting point. Participants were instructed to walk as normally as possible through a 12 m distance gait path, with the first 4 m being used for acceleration and the last 2 m for deceleration. The usual gait speed was calculated by dividing 6 m by the time taken to pass between the phototubes. The 5-time chair stand test was performed using a stopwatch by the same examiner for all subjects. Participants were instructed to stand up and sit down as fast as possible in five repetitions from a chair with 40-cm height with their arms crossed, and the time taken to stand up and sit down was measured. The SPPB score was calculated based on the standing balance test (quiet standing with feet closed, semi-tandem, and tandem standing), 6 m gait speed, and 5-time chair stand test.

Lower limb muscle strength measurement

The lower limb muscle strength of the right side was measured from the maximum voluntary isometric contraction using a dynamometer (Musculater, OG Giken Co., Okayama, Japan) or a hand-held dynamometer (HHD; hand-held dynamometry Mobie, Sakai Iryou Co., Ltd., Tokyo, Japan). In lower limb muscle strength measurements, the subjects were instructed to exert force as hard as possible with their maximum voluntary isometric contraction for 3 s after the participants were familiarized with maximal isometric contraction by pre-measurement trials. A resting period of approximately 30 s was provided between the two measurements of strength taking fatigue into consideration. Lower limb muscle strength was measured by a well-trained physical therapist. The obtained value multiplied by the moment arm was calculated as the torque (Nm). Muscle strength was measured twice, and the larger value was used for analysis.

(1) Knee extensor muscle strength
Knee extensor muscle strength was measured in the sitting position on a chair with 90-degree flexion of the knee joints. The sensor of the dynamometer was applied to the lower leg, 25 cm distal to the knee joint space.

(2) Hip flexor muscle strength
The hip flexor muscle strength was measured in the sitting position on a chair with 90-degree flexion of the hip and knee joints. The HHD sensor was applied to the distal thigh.

(3) Hip abductor muscle strength
The hip abductor muscle strength was measured at hip abduction angle of 0° with the hip and knee fully extended in the supine position. The sensor of the dynamometer was applied to the lower leg, 5 cm proximal to the lateral malleolus.

Balance ability measurement

One-leg standing time and timed up and go (TUG) tests were used to measure balance ability. One-leg standing time was determined by measuring the time of standing on the dominant foot with the eyes open. The measurement was performed twice with an upper limit of 60 s, and the longer time was used for statistical analysis. One-leg standing time was measured by the same examiner.

TUG was measured for the time required where the participants were instructed to stand up from a chair, walk 3 m to a pole, turn around the pole, return to the chair, and then sit down as quickly as possible.

Classification of sarcopenia stage

Sarcopenia stage was classified according to the AWGS 2019 criteria. Low muscle mass was evaluated using SMI, which is considered a reliable method of estimating muscle mass [15] and is defined as being SMI <7.0 kg/m^2 in men, and SMI < 5.7 kg/m^2 in women. Weak muscle strength is defined as handgrip strength ≤ 28.0 kg for men and ≤ 18.0 kg for women. Poor physical performance is defined as a usual gait speed ≤ 1.0 m/s, SPPB ≤ 9, or 5-time chair stand test ≥ 12 s. Sarcopenia was diagnosed in participants with weak handgrip strength or poor physical performance, in addition to a low SMI. Furthermore, individuals with only low SMI were classified in "the low muscle mass group," and those without low SMI but with only poor grip strength or poor physical performance were classified in "the low physical function group." The participants were classified into four groups: normal, low muscle mass, low physical function, and sarcopenia groups.

Statistical analyses

Values are presented as mean ± standard deviation. To compare the knee extensor muscle strength, hip abductor muscle strength, hip flexor muscle strength, one-leg standing time, and TUG between sarcopenia stage groups, we performed an analysis of covariance adjusted for age and body mass index. When a main effect was detected, between-group comparisons were performed using Bonferroni's multiple comparisons.

All statistical analyses were performed using SPSS Statistics for Windows, version 22.0 (Armonk, NY: IBM Corp.). *P* values < 0.05 were considered statistically significant.

Table 1 Numbers of participants according to sarcopenia stage

n, (%)	Total *n* = 2107	Men *n* = 738	Women *n* = 1369
Normal	1433 (68.0)	499 (67.6)	934 (68.2)
Low muscle mass (LM)	315 (15.0)	98 (13.3)	217 (15.9)
Low physical function (LF)	227 (10.8)	97 (13.1)	130 (9.5)
Sarcopenia	132 (6.2)	44 (6.0)	88 (6.4)

Results

The results of participant classification into the sarcopenia stage according to the AWGS 2019 algorithm are shown in Table 1. The normal group comprised 68.0% (men, 67.6%; women, 68.2%), the low muscle mass group comprised 15.0% (men 13.3%, women 15.9%), the low physical function group comprised 10.8% (men 13.1%, women 9.5%), and the sarcopenia group comprised 6.2% (men 6.0%, women 6.4%). There were no sex-related differences in the proportions of each group. Participants in the low muscle mass, low physical function, and sarcopenia groups were older than those in the normal group in both men and women (Tables 2, 3).

Multiple comparisons showed that SMI in the sarcopenia and low muscle mass groups was lower than that in the normal and low physical function groups both in both men and women. Grip strength, SPPB, and 5-time chair stand were lower in the sarcopenia and low physical function groups than in the normal and low muscle mass groups in both men and women. Usual gait speed was lower in the sarcopenia and low physical function groups than in the normal group in both men and women. For usual gait speed, SPPB, and 5-time chair stand, there was no significant difference between the normal and the low

Table 2 Characteristics in older men by sarcopenia stage (mean ± SD)

	Normal *n* = 499	Low muscle mass *n* = 98	Low physical function *n* = 97	Sarcopenia *n* = 44
Age (years)	68.2 ± 5.1	71.2 ± 5.1†	71.9 ± 4.7†	74.0 ± 4.4†‡
BMI (kg/m^2)	23.6 ± 2.5	20.1 ± 2.0†	23.8 ± 2.7‡	21.3 ± 2.3†‡§
SMI (kg/m^2)	7.8 ± 0.5	6.6 ± 0.7†	7.6 ± 0.5‡	6.4 ± 1.0†§
Grip strength (kg)	40.3 ± 5.7	34.8 ± 4.0†	32.3 ± 6.4†‡	28.1 ± 5.4†‡§
Usual gait speed (m/s)	1.5 ± 0.3	1.5 ± 0.2	1.4 ± 0.2†	1.2 ± 0.3†‡
SPPB (score)	11.9 ± 0.2	11.9 ± 0.3	11.7 ± 0.6†‡	11.4 ± 0.8†‡§
5-time chair stand (s)	8.1 ± 1.7	8.3 ± 1.6	12.5 ± 3.0†‡	13.1 ± 5.2†‡
Balance function				
Timed up and go (s)	6.3 ± 1.1	6.5 ± 0.9	7.3 ± 1.3†‡	8.7 ± 3.0†‡§
One-leg stand (s)	37.8 ± 22.7	35.6 ± 22.3	27.7 ± 23.1	20.8 ± 20.8†
Lower extremity muscle strength				
Hip flexion (Nm)	56.7 ± 18.0	48.6 ± 15.7†	45.2 ± 14.7†	39.1 ± 15.1†
Hip abduction (Nm)	112.4 ± 26.6	93.2 ± 22.0†	92.3 ± 26.4†	72.2 ± 21.0†‡§
Knee extension (Nm)	173.2 ± 53.6	136.2 ± 38.5†	134.8 ± 42.1†	103.3 ± 39.2†‡

† significant difference compared with Normal, ‡ significant difference compared with low muscle mass, § significant difference compared with low physical function, *p* < *0.05*

Table 3 Characteristics in older women by sarcopenia stage (mean ± SD)

	Normal $n = 934$	Low muscle mass $n = 217$	Low physical function $n = 130$	Sarcopenia n = 88
Age (years)	66.8 ± 4.9	68.7 ± 5.4†	69.8 ± 5.0†	71.3 ± 5.3†‡
BMI (kg/m²)	22.6 ± 2.9	19.3 ± 1.9†	23.6 ± 3.0†‡	20.0 ± 3.1†‡§
SMI (kg/m²)	6.3 ± 0.4	5.3 ± 0.4†	6.3 ± 0.4‡	5.1 ± 1.0†‡§
Grip strength (kg)	24.2 ± 3.4	22.2 ± 3.4†	20.3 ± 4.0†‡	17.3 ± 3.2†‡§
Usual gait speed (m/s)	1.5 ± 0.3	1.5 ± 0.2	1.4 ± 0.2†	1.3 ± 0.3†‡
SPPB (score)	11.9 ± 0.2	11.9 ± 0.09	11.7 ± 0.7†‡	11.7 ± 0.3†‡
5-time chair stand (s)	7.9 ± 1.6	7.9 ± 1.6	11.7 ± 3.0†‡	10.9 ± 3.6†‡
Balance function				
Timed up and go (s)	6.4 ± 1.2	6.4 ± 0.9	7.3 ± 1.2†‡	7.8 ± 2.0†‡
One-leg stand (s)	41.8 ± 21.4	39.7 ± 21.6	30.2 ± 22.8†	29.8 ± 22.3†
Lower extremity muscle strength				
Hip flexion (Nm)	37.7 ± 10.2	33.5 ± 9.2†	30.2 ± 9.1†	27.3 ± 8.2†‡§
Hip abduction (Nm)	74.1 ± 17.9	62.9 ± 15.9†	59.0 ± 16.6†‡	54.6 ± 15.8†‡
Knee extension (Nm)	99.0 ± 28.8	82.6 ± 26.2†	82.9 ± 26.8†	66.8 ± 20.6†‡§

† significant difference compared with Normal, ‡ significant difference compared with low muscle mass, § significant difference compared with low physical function, $p < 0.05$

muscle mass groups both in men and women (Tables 2, 3).

The analysis of covariance using age and BMI as covariates showed that the main effect was observed in all lower limb muscle strength in both men and women. Multiple comparisons showed that all lower limb muscle strengths were significantly lower not only in the sarcopenia group but also in the low muscle mass and low physical function groups than that in the normal group. Knee extensor muscle strength and hip abductor muscle strength were significantly greater in the low muscle mass group than in the sarcopenia group. Regarding sex differences, lower hip flexor muscle strength was noted in the sarcopenia group than in the low muscle mass and low physical function groups for women, but not for men. In addition, weaker hip abductor muscle strength was observed in the low physical function group than in the low muscle mass group in women, but not in men (Fig. 2).

As for balance ability, the analysis of covariance showed main effects in all balance ability assessments in both men and women. Multiple comparisons showed that the measurements of all balance ability assessments were significantly worse in the sarcopenia group than in the normal group. The TUG was significantly slower in the sarcopenia and the low physical function groups than in the low muscle mass and the normal groups in both men and women. A poorer one-leg standing time was observed in the low physical function group than in the normal group in women, but not in men (Fig. 2).

Discussion

This study is the first to clarify sex-related differences in motor function among sarcopenia stages, especially the differences between the low muscle mass group and the low physical function group.

Differences in the motor function between sarcopenia stages

Similar to our hypothesis, the characteristics of motor function differed between the low muscle mass and low physical function groups, and between the normal and sarcopenia groups. First, all of the measurements of the lower limb muscle strength and balance ability in the sarcopenia group were lower than in the normal group in both men and women. Muscle strength was weaker not only in the sarcopenia group but also in both the low muscle mass and low physical function groups. In balance ability, TUG in the low physical function group was poorer than in the normal group, in both men and women, whereas there were no significant differences in TUG and one-leg standing time between the low muscle mass and normal groups. Thus, older adults with only muscle mass loss may have less balance ability loss, but muscle weakness may be significant. These results suggest that lower limb strength training may be required for older people who have not

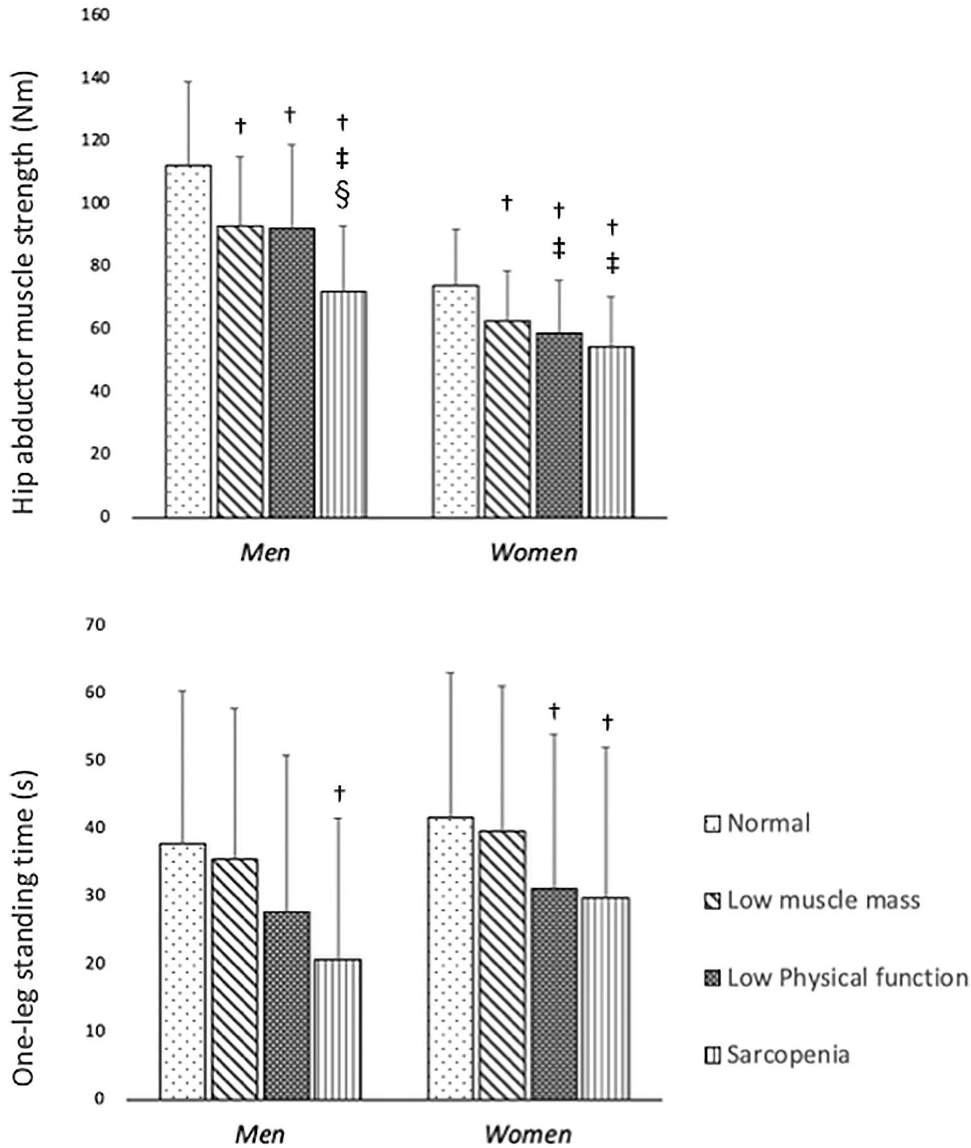

Fig. 2 Comparisons of hip abductor muscle strength and one-leg standing time between sarcopenia stage groups in men and women. †Significant difference compared with Normal, ‡significant difference compared with low muscle mass, §significant difference compared with low physical function, †‡§$p < 0.05$.

reached the sarcopenia stage, and that balance training may be required in addition to lower limb strength training, especially in older people with physical functional deterioration.

Previous studies reported that TUG was slower in community-dwelling older adults with low muscle function, but not in older adults with low muscle mass [7, 13]. Furthermore, Benavent-Caballer et al. [16] reported that TUG is associated with knee extension muscle strength, but not with quadriceps muscle thickness. Age-related decline in muscle strength is greater than muscle mass, and this is because neural factors such as the number of motor unit recruitments and rate coding play a more important role in muscle function rather than muscle mass in older adults [17]. Therefore, TUG, which is significantly associated with neural factors such as neuromuscular coordination, seems to be significantly poorer in older adults with low muscle function than in older adults with low muscle mass.

Furthermore, TUG was slower in the low physical function group than in the normal group in both men and women, but one-leg standing in men was not significantly different between these two groups. One-leg standing time is considered an index of static balance ability and TUG an index of dynamic balance [18], suggesting that dynamic balance ability is more likely to be reduced than static balance ability in older adults with low physical function. Among the low physical function group, many participants had a reduction in 5-times chair stand test time and a reduction in normal gait speed. The 5-times chair stand test and gait speed have been reported to be related to muscle power [19–21]. Muscle power is also required in the TUG test, which involves standing up and walking as quickly as possible. Therefore, it is likely that the low function group had reduced dynamic balance ability, such as TUG, which is needed to move quickly.

Sex-related differences in the motor function

Corresponding to our hypothesis, there were sex-related differences in the association between sarcopenia stages and motor function. The hip abductor muscle strength in the low function group was lower than that in the low muscle mass group, and one-leg standing time was lower in the low function group than in the normal group. Previous studies have shown that women have a lower ability to control standing posture on the frontal plane than men [22], and hip abductor muscle strength is related to standing balance ability or fall risk [23–25]. In the present study, the one-leg standing time was poorer in the low function group than in the normal group in women. Our results suggest that poor static balance ability, such as the one-leg standing ability in older women with low physical function, may be due to reduced hip abduction muscle strength. In addition, the present study showed weaker hip flexor muscle strength in the sarcopenia group than in the low muscle mass and low physical function groups, only in women. These results suggest that the decline in lower limb muscle strength and balance ability in the low physical function and sarcopenia groups may be greater in older women. Therefore, especially for older women, strength and balance training are recommended in the early stages of physical deterioration to maintain motor function.

Limitation

The limitation of the present study is that the characteristics of motor function were assessed in terms of only two factors: the muscle strength of the lower limb and balance ability. Future studies need to clarify the characteristics of each sarcopenia stage from multiple perspectives, including motor function other than lower limb muscle strength, balance ability, and cognitive and psychological factors.

Conclusion

We investigated the sex-related characteristics of motor function by sarcopenia stage, especially in older adults who have greater risk for developing sarcopenia due to low muscle mass or low physical function. Our results showed that not only the sarcopenia group, but also the low muscle mass and low physical function groups had lower muscle strength, and that dynamic balance ability tended to be more reduced in the low physical function group than in the low muscle mass group. In addition, the characteristics of lower limb muscle strength and balance ability according to the sarcopenia stage tended to differ between the sex. Our results suggest that sarcopenia stages and sex need to be considered when prescribing exercise for older adults.

Author contributions TK: conceptualization, methodology, formal analysis, investigation, and writing (original draft). TI: conceptualization, methodology, formal analysis, investigation, and writing (original draft). YT: conceptualization; writing, reviewing, and editing; supervision. FM: supervision. TT: conceptualization, writing, reviewing, and editing. NI: conceptualization; methodology; formal analysis; writing, reviewing, and editing; project administration.

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Availability of data and material Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no competing interest.

Ethics approval The study protocol was approved by the ethics committee of the Kyoto University Graduate School of Medicine and by the Nagahama Municipal Review Board.

Consent to participate The content of the study was explained to the participants, and written informed consent was obtained from them.

Consent for publication Not applicable.

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