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Original Article

Development of Estimate Formulas for Appendicular Lean Mass Using Forearm Circumference in Older Adults Requiring Care

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Abstract

Objectives: The use of forearm circumference (FC) in the estimation equation to predict appendicular lean mass (ALM) in older adults who require care remains unclear. **Methods**: This cross-sectional study targeted 132 participants aged ≥65 years requiring care. The ALM was measured with bioelectrical impedance analysis (BIA). Handgrip strength (HS) was measured with a digital hand dynamometer. FC was measured at the site of maximum swelling using a tape measure. Multiple regression analysis was conducted to develop an equation for estimating BIA-measured ALM using FC. Moreover, we investigated a systematic error by Bland–Altman analysis between BIA-measured ALM and ALM calculated by the estimation equation. **Results**: We developed the four estimation equations. The values of r, adjusted R^2, and SEE in the representative model (FC + HS + age) were 0.86, 0.73, and 2.01 (kg), respectively ($p < 0.05$). In contrast, a systematic error was identified between the BIA-measured ALM and ALM calculated by the estimation equations by the Bland–Altman analysis. **Conclusions**: This study developed the formula using FC, which can predict ALM with less influence of edema, but it may over- or underestimate ALM in older adults requiring care.

Keywords: Appendicular lean mass, Estimated formula, Forearm circumference, Long-term care, Older adults requiring care

Introduction

Sarcopenia has gained attention in recent years with an aging population. Sarcopenia is the age-related loss of skeletal muscle mass and is presented as low skeletal muscle mass and low muscle strength or/and low physical function in old age. Complications of sarcopenia increase the risk of falls, fractures, and frailty and even affect prognosis[1,2]. The prevalence of sarcopenia in community-dwelling older adults is approximately 7%–10%[3,4]. Additionally, other studies have revealed as much as 10%–16% of the elderly globally[5]. Moreover, the older adults requiring care, with the condition that needs some kind of assistance in daily living (frailty is defined as a previous stage of the conditions requiring care in Japan), exhibited a higher percentage of sarcopenia (37.5%)[6]. Further, approximately 87% of the total older individuals who require care (54/62) were reported to experience sarcopenia complications (pure sarcopenia and severe sarcopenia)[7]. Thus, preventing the complication of sarcopenia in older adults requiring care is particularly important.

The diagnosis of sarcopenia requires muscle mass, muscle strength, and physical function measurement. Muscle mass is generally measured with dual-energy x-ray absorptiometry or bioelectrical impedance analysis (BIA). However, the machines are expensive, and the

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measurements must be taken standing up, etc. Some elderly people requiring care are unable to maintain their standing. Therefore, a more convenient method for measuring the muscle mass is warranted.

Limb circumference is an indicator that reflects muscle mass and can be easily measured with a tape measure. Calf circumference (CC) is an alternative for measuring muscle mass, which is necessary for determining the presence of sarcopenia in the Asian Working Group for Sarcopenia 2019[8]. Additionally, equations for estimating muscle mass using CC have been developed[9,10]. However, CC is easily affected by gravity because of its location on the peripheral part of the lower limbs. We frequently encounter elderly people with edematous lower legs. Therefore, the estimation of muscle mass by CC may be prone to errors caused by edema.

Our previous study revealed that not only CC but also the upper arm circumference (UC), forearm circumference (FC), and thigh circumference (TC) were positively associated with muscle mass[11]. UC and TC may not be measured due to the inability to roll up clothing. The area of FC is relatively easy to expose to the skin and is less affected by edema compared with CC. FC could be utilized as a substitute for lower leg circumference for measuring muscle mass in older adults requiring care, but little is known about whether FC can be used in the estimation equation to predict muscle mass. Developing the estimation equation to predict muscle mass using FC caused a more accurate estimation of muscle mass with lesser edema effect.

This study aimed to determine the use of FC as a muscle mass predictor and to develop a formula for estimating muscle mass using FC in older adults requiring care.

Materials and Methods

Participants

This cross-sectional study recruited 134 participants aged 65 years who require care. They regularly visited one of the four adult day facilities using long-term care insurance in Japan from July 2022 to April 2024. This study excluded participants who 1) could not complete measurements, 2) had difficulty walking alone (except with supervision), and 3) were pacemaker users. Finally, the analysis included 132 participants after excluding 2 participants due to incomplete measurement. Long-term care insurance in Japan involved seven severity levels (support levels 1 and 2 and care levels 1, 2, 3, 4, and 5), wherein care level 5 was judged as the most severe. The severity level for long-term care is usually judged by converting the time and effort it takes to care in time. The time is calculated as follows: 1) direct assistance with daily living (e.g., bathing), 2) indirect assistance with daily living (e.g., laundry), 3) problematic behavior-related activities (e.g., search for wandering), 4) functional training related activities (e.g., walking practice), 5) medical care-related activities (e.g., infusion management). In addition, cognitive indicators are taken into account to determine the level of care required[12]. The standard times are >25 min to <32 min for support level 1 and >110 min for care level 5. The number of our participants in each level was10 (support level 1), 12 (support level 2), 62 (care level 1), 29 (care level 2), 11 (care level 3), 5 (care level 4), and 3 (care level 5).

Appendicular lean mass (ALM)

ALM, measured with BIA (TANITA, MC-780 AN, Tokyo, Japan), is one of the methods listed for measuring muscle mass in the Asian Working Group for Sarcopenia 2019[8]. The participant was instructed to stand barefoot on the machine and was automatically weighed. Next, they entered their age, gender, and height into the machine and then gripped the handle with both hands to measure ALM.

Handgrip strength (HS)

HS was measured with a digital hand dynamometer (Grip-D, Takei, Niigata, Japan). The measurement position was sitting with the elbows extended along the side of the body. Both the left and right sides were measured twice at maximum effort, and the highest value out of four was considered for analysis.

Forearm Circumference (FC)

FC was measured at the site of maximum swelling with a tape measure (0.1 cm intervals). The measurement position was sitting with the elbows extended along the side of the body with the hands in a neutral position. Both the left and right sides were measured twice, and their average values were calculated, and the higher value of either side was adopted for analysis. The intraobserver and inter-observer reliability of circumference measurements ranged from good to perfect (0.65–0.99) and perfect (0.92–0.99), respectively[13].

Statistical Analysis

The data are expressed as mean ± standard deviation. Statistical analyses were conducted using IBM Statistical Package for the Social Sciences version 29.0 for Mac (IBM Corp., Tokyo, Japan). The male and female were used for the unpaired t-test for characterization. Besides, the Pearson product-moment correlation coefficient was conducted to confirm the association between the BIA-measured ALM and each measured item. Multiple regression analysis was then used to develop an equation for estimating BIA-measured ALM using FC. First, an estimation equation for FC only was developed (dependent variable: BIA-measured ALM). We then developed estimating equations with BIA-measured ALM as the dependent variable and the data that were significant in the correlation analysis as explanatory variables (stepwise method). Moreover, we investigated a systematic error by Bland–Altman analysis between BIA-measured ALM and

	All (n = 132)	Male (n = 55)	Female (n = 77)	*P–values*
Age (years)	85.1 ± 6.7	82.8 ± 7.7	86.8 ± 5.4	<0.001
Height (cm)	152.0 ± 10.2	161.3 ± 7.7	145.4 ± 5.6	<0.001
Weight (kg)	50.6 ± 10.9	57.2 ± 11.6	45.8 ± 7.4	<0.001
BMI (kg/m^2)	21.7 ± 3.5	21.8 ± 3.7	21.6 ± 3.7	0.765
HS (kg)	18.4 ± 7.6	24.9 ± 6.8	13.8 ± 3.8	<0.001
ALM (kg)	14.0 ± 3.9	16.9 ± 4.0	11.9 ± 1.9	<0.001
FC (cm)	21.5 ± 2.3	23.0 ± 2.0	20.4 ± 1.8	<0.001

BMI: body mass index; HS: handgrip strength; ALM: appendicular lean muscle; FC: forearm circumference.

Table 1. The characteristics of the participants of this study (n = 132).

	Age	Height	Weight	BMI	HS	ALM	FC
Age		-0.45**	-0.36**	-0.08	-0.45**	-0.49**	-0.38**
Height	-0.45**		0.64**	0.002	0.77**	0.87**	0.60**
Weight	-0.36**	0.64**		0.76**	0.66**	0.81**	0.88**
BMI	-0.08	0.002	0.76**		0.20*	0.31**	0.65**
HS	-0.45**	0.77**	0.66**	0.20*		0.80**	0.71**
ALM	-0.49**	0.87**	0.81**	0.31**	0.80**		0.77**
FC	-0.38**	0.60**	0.88**	0.65**	0.71**	0.77**	

* $p < 0.05$, ** $p < 0.01$. *BMI: body mass index; HS: handgrip strength; ALM: appendicular lean muscle; FC: forearm circumference.*

Table 2. Correlation coefficients between ALM and each item in this study (n = 132).

	Estimated Formulas	*r*	Adjusted R^2	SEE (kg)	*P* value
Model 1	-14.151 + 1.309 × FC (cm)	0.77	0.59	2.47	<0.001
Model 2	6.537 + 0.405 × HS (kg)	0.80	0.63	2.35	<0.001
Model 3	-5.922 + 0.256 × HS (kg) + 0.707 × FC (cm)	0.85	0.72	2.06	<0.001
Model 4	1.706 + 0.231 × HS (kg) + 0.677 × FC (cm) + -0.077 × age (year)	0.86	0.73	2.01	<0.001

Model 1: FC (cm); model 2: HS (kg); model 3: FC (cm) + HS (kg); model 4 : FC (cm) + HS (kg) + age (year). *ALM: appendicular lean mass; FC: forearm circumference; HS: handgrip strength; SEE: standard error of estimate.*

Table 3. Estimation equations to predict ALM with FC by multiple regression analysis (n = 132).

ALM calculated by the estimation equations. *P*-values of <0.05 were set as statistically significant.

Results

Table 1 presents the characteristics of the participants of this study. The female participants were significantly older than the male participants in this study ($p < 0.05$). HS, ALM, and FC were significantly higher in male participants compared with those in female participants ($p < 0.05$). Table 2 shows the correlation coefficients among various items in this study. Significant correlations were observed between BIA-measured ALM and age, height, weight body mass index (BMI), HS, and FC (r = -0.49, 0.87, 0.81, 0.31, 0.80, and 0.77, all $p < 0.05$).

A multiple regression analysis was conducted with BIA-measured ALM as the dependent variable and the variables

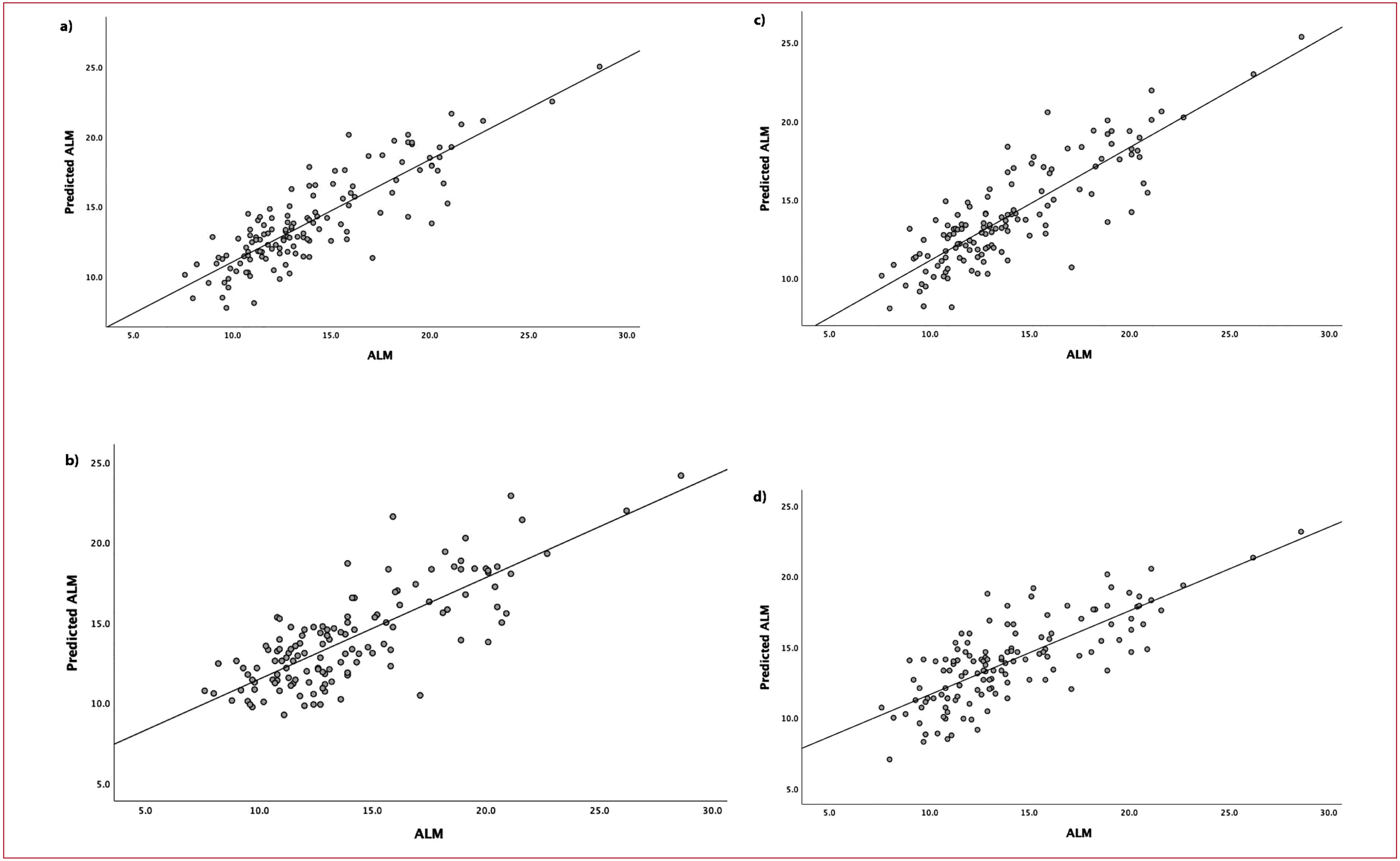

Figure 1. Correlation between ALM and predicted ALM in a) model 1 (FC) (n = 132) b) model 2 (HS) (n = 132) c) model 3 (FC + HS) (n = 132) d) model 4 (FC + HS + age) (n = 132). ALM: appendicular lean mass; FC: forearm circumference; HS: Handgrip strength.

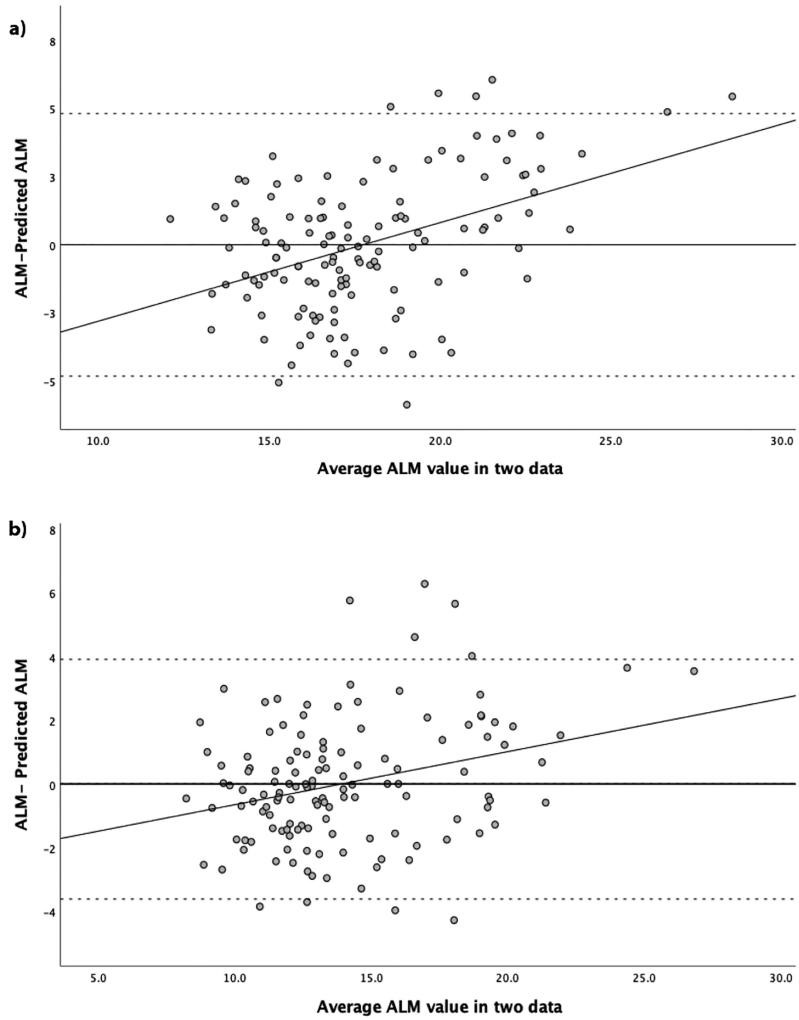

Figure 2. Bland-Altman analysis between ALM and predicted ALM using a) model 1 (FC) (n =132) b) model 4 (FC + HS + age) (n =132). ALM: appendicular lean mass; FC: forearm circumference; HS: handgrip strength.

that were significant in the correlation (BMI was adopted among height, weight, and BMI) and sex (male=1, female=2) as explanatory variables to develop the estimating equation. FC, HS, and age were extracted in the estimated equations using multiple regression analysis (stepwise method), and we developed models 1 (FC), 2 (HS), 3 (FC and HS), and 4 (FC, HS, and age) as estimation formulas (Table 3). The values of r were 0.77, 0.80, 0.85, and 0.86, adjusted R^2 were 0.59, 0.63, 0.72, and 0.73, and SEE were 2.47, 2.35, 2.06, and 2.01 (kg) in models 1, 2, 3, and 4, respectively (Table 3, all $p < 0.05$). The correlation coefficients of BIA-measured ALM and ALM predicted by the estimation equation were 0.77 (model 1, Figure 1a), 0.80 (model 2, Figure 1b), 0.85 (model 3, Figure 1c), and 0.86 (model 4, Figure 1d), respectively (all $p < 0.05$).

Moreover, we performed Bland–Altman analysis to check the systematic errors, and two representative figures are shown (Figures 2a and 2b). The mean differences between the ALM and the predicted ALM in models 1, 2, 3, and 4 were not significantly different (model 1: mean difference: -0.0003, 95% confidence interval (CI):-0.424–0.423, p = 0.999; model 2: mean difference: -0.0063, 95% CI: -0.4048–0.3922, p = 0.975; model 3: mean difference: -0.0034, 95% CI: -0.351–0.3447, p = 0.985; model 4: mean difference: 0.0300, 95%CI: -0.3123–0.3724, p = 0.862). Conversely, significant correlations were observed between the difference between ALM and predicted ALM and the value of average ALM in all models (model 1: r = 0.425; model 2: r = 0.355; model 3: 0.296; model 4: r = 0.289, all $p < 0.05$).

Discussion

This study revealed a strong correlation between ALM and FC using the Pearson product-moment correlation coefficient. Besides, we developed an estimation formula to calculate ALM using FC. Conversely, a systematic error was determined between the BIA-measured ALM and the ALM calculated by the estimation equation using FC by Bland–Altman analysis. The formula using FC could predict ALM with fewer effects of edema, and notably, it may over- or underestimate ALM in older adults requiring care.

This study developed formulas for estimating ALM, but systematic error was observed between BIA-measured ALM and ALM calculated by estimation equations using Bland–Altman analysis (all models). A previous study revealed the r, adjusted R^2, and SEE of the estimation equation predicting the appendicular skeletal muscle mass by calf circumference, waist circumference, sex, height, and weight as 0.969, 0.938, and 1.15 kg, respectively. Additionally, they revealed a significant weak correlation between the ASM and the predicted ASM using the estimation equation observed by Bland–Altman analysis (men, r = 0.35; women, r = 0.02; mixed-sex, r = 0.15)[10]. Besides, another study on estimating equations to predict ALM using circumference found r, adjusted R^2, and SEE to be 0.93, 0.93, and 1.33 kg, respectively[14]. Furthermore, previous studies that used BMI to estimate ASM revealed adjusted R^2 and SEE of 0.906 and 1.87 kg, respectively[15]. Our study revealed the same systematic errors as previous studies and the error level was larger than in previous studies. Thus, the estimation equations in this study need to be used to account for the possibility of over- or underestimation of ALM in older adults requiring care, and future studies are warranted to develop more accurate estimation formulas.

One possible factor of systematic error is the body size. However, the average BMI of male (an average age of 82.8 years) and female (an average age of 86.8 years) participants in this study were 21.8 kg/m^2 and 21.6 kg/m2, respectively. The average BMI in Japanese people, which ranged from 80 to 84 years for males and females ≥85 years was 20.94 kg/m^2 and 20.19 kg/m^2, respectively[16]. The physique of both male and female participants in this study was larger than the average value of Japanese people of the same age, they were not classified as obese or thin, but as a standard physique. The muscle areas, as other factors of systematic error that are most likely to be affected by aging and immobility, involved the lower extremities compared to the upper extremities[17,18]. ALM includes the lower limb muscle mass in this study. Moreover, individual differences in FC (male: minimum 17.6 cm to maximum 28.5 cm; female: minimum 16.2 cm to maximum 25.5 cm in this study) are less than in CC (male [80–84 years old]: minimum 23.0 cm to maximum 39.0 cm; female (≥85 years old): minimum 18.0 cm to max 35.0 cm][19]. Therefore, the FC could have been lower if the ALM is large, causing a larger mean difference, and the FC could have been larger if the ALM is small, causing a smaller mean difference due to little change in the FC relative to the increase or decrease in the ALM.

Our study has several limitations. First, it includes a small number of participants. Thus, more participants need to be targeted in future studies. Second, it includes participants with various severity levels, and the severity level of the participants should be better aligned in future studies. Third, it targets only Japanese nationals, and applying it directly to people of other races is considered difficult.

Conclusions

We developed estimation formulas to calculate ALM using FC, which were used to predict ALM with less influence of edema. However, Bland–Altman analysis revealed the same systematic errors as those in previous studies, and the error levels were larger than in previous studies. Therefore, the estimation equations in this study need to be used to account for the possibility of over- or underestimation of ALM in older adults requiring care.

Ethics approval

The Ethics Committee of the Health Science University approved this study (Approval No: R1-016 and R2-004).

Consent to Participate

All participants read and signed an informed consent form.

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Authors' contributions

Daisuke Takagi: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Writing-original draft, Writing-review & editing, Supervision, Project administration, Funding acquisition. Masatoshi Kageyama: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Writing-original draft, Writing-review & editing. All authors read and approved the final version of the manuscript.

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