Original Article

Association between upper limb muscle quality and knee osteoarthritis in dynapenia: an observational cross-sectional study

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(Received 3 April, 2024; Accepted 4 May, 2024; Released online in J-STAGE as advance publication 8 May, 2024)

Neurological and skeletal muscle properties are suggested causes of dynapenia. This study aimed to evaluate the relationship between upper limb muscle quality (grip strength/upper extremity muscle mass) and knee osteoarthritis in dynapenia, and to identify dynapenia-associated factors. Elderly individuals who responded to a public call for screening in Wakasa Town, Fukui Prefecture between June 2019 and November 2021 were included. The analysis included 433 participants (304 women aged 76.0 ± 7.1 years). Examination comprised (consecutively) a basic interview, physical function measurement, body composition measurement, and explanation of results. Dynapenia was observed in 67 patients. Binomial logistic regression analysis revealed that age, upper limb muscle quality score, and knee osteoarthritis were independent factors for dynapenia. Receiver operating characteristic analysis of the relationship between dynapenia and upper limb muscle quality showed an area under the curve of 0.806 (95% confidence interval: 0.658–0.953) for men (cut-off value, 14.3 kg/kg) and 0.849 for women (95% confidence interval: 0.858–0.968; cut-off value, 14.0 kg/kg). In conclusion, age, upper limb muscle quality, and knee osteoarthritis were independent factors of dynapenia. We demonstrated that upper limb muscle quality has good accuracy in detecting dynapenia in both men and women.

Key Words: **dynapenia, upper limb muscle quality, knee osteoarthritis, aging**

The global population is rapidly aging, and physical limitations increase with age.[1] Japan's aging rate is rapidly increasing, making it the most aging country worldwide.[2] These demographic changes increase physical limitations and affect Japan's social security system, especially in medical care, long-term care, and local economies.[1] This number is projected to increase continuously. Physical limitations cause decreased mobility, an increased risk of falls, and a decreased overall quality of life,[3–6] thereby increasing the risk of institutionalization, prolonged hospitalization, and early mortality.[7–9] Dynapenia is a geriatric syndrome characterized by an age-related decline in muscle function (muscle weakness/physical function decline).[10,11] Two factors are reported to cause dynapenia: neurological and skeletal muscle properties.[10] However, the definitions and mechanisms of risk factors for dynapenia remain unclear.

An increase in osteoarthritis (OA) and dynapenia has been reported, owing to the socioeconomic impact of aging.[12] Osteoarthritis is the most common joint disease affecting mainly the movable joints.[12] Muscle weakness in OA is attributed to muscle atrophy, and is considered secondary to pain.[13] Muscle weakness has also been reported to be associated with an increased risk of OA in both men and women.[14] Patients with OA exhibit systemic symptoms that may lead to loss of muscle strength, muscle mass, and ultimately muscle function.[15] Decreased grip strength in men and women was negatively correlated with hand (both $p<0.001$) and knee OA (men, $p<0.001$; women, $p = 0.010$), and a significant association between decreased grip strength and OA was also reported.[16] Dynapenia has been determined using skeletal muscle mass index (SMI) measurements for muscle mass assessment, grip strength measurements for muscle strength assessment, and gait speed and five-fold rise measurement for physical function assessment.[17,18] In OA, a decrease in grip strength and walking speed is assumed, which may be related to dynapenia.

Changes in skeletal muscle with aging suggest that not only changes in quantity but also factors, such as muscle quality, are involved in the decline in skeletal muscle function and mobility.[19] As skeletal muscle quality is strongly affected by aging, it is important to evaluate skeletal muscle quality in the elderly. Studies on muscle quality are underway.[20] Muscle quality in dynapenia can be quantitatively assessed using ultrasonography.[20] There are several methods of evaluating muscle quality, including evaluation of efficiency calculated from grip strength divided by upper limb muscle mass [upper limb muscle quality (ULMQ)], visual evaluation based on differences in luminance using ultrasound images, and evaluation of phase angle using the bioelectrical impedance analysis (BIA) method.[20,21]

This study focused on the ULMQ body composition index. To

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doi: 10.3164/jcbn.24-58

the best of our knowledge, there have been no reports on the use of ULMQ in the detection of dynapenia. This study aimed to evaluate the relationship between ULMQ and knee OA in dynapenia, and to identify new factors associated with dynapenia. We also attempted to determine the cut-off values for ULMQ to detect dynapenia. This study will contribute to the prevention of dynapenia and establishment of treatment strategies.

Materials and Methods

Participants. A total of 1,088 participants who responded to an open call to screen older individuals in Wakasa Town, Mikata-Kaminaka County, Fukui Prefecture, between June 2019 and November 2021 were included in the study. The first examination included 633 patients, 68 of whom were cardiac pacemaker users or had missing data on anthropometers (phase angle, etc.). Additionally, an outlier test showed one outlier in the SMI value, which was removed. Therefore, 545 participants were included in the analysis. Analysis of the independent factors of dynapenia was performed on 433 patients in two groups, including dynapenia and robust, excluding 86 patients with presarcopenia and 45 with sarcopenia.

Methods. After obtaining written consent from those who responded to an invitation, examination consisted of a basic interview, physical function measurements (walking speed, grip strength, and height), body composition measurement using the BIA method, and explanation of the results, in that order. A basic questionnaire included age, sex, medical history, and lifestyle (smoking and alcohol consumption). Time taken to pass a 5 m point without decelerating was measured, and walking speed was calculated from this time. A Smedley-type digital hand dynamometer (TTM; Tsutsumi Seisakusyo Co., Ltd., Tokyo, Japan) was used to measure grip strength. Grip strength was measured on both sides, and the maximum value was adopted. Body composition was measured using a body composition analyzer (MC-780A-N and MC-780A; TANITA Co., Ltd., Tokyo, Japan). The body composition analyzer measures muscle mass, fat mass, and body water content from a precise analysis of the cell's interior and exterior fluid, using three multi-frequency measurements (5 kHz, 50 kHz, or 250 kHz) and reactance analysis, which provides electrical information about the cell membrane. Body mass index (BMI) is a measure of body weight (kg) divided by the square of height (m). Limb skeletal muscle mass is a measure of the total muscle mass of the extremities. Skeletal muscle mass index is an index of limb skeletal muscle mass (kg/m^2) divided by the square of height (m). Bone mass (bone mineral content) is a statistically estimated index based on correlation with the amount of tissue other than fat (lean body mass). Phase angle is the angle calculated by deriving the impedance from the magnitude of the phase shift (reactance) generated in the muscle cell when a weak current passes through it and the value of resistance, which is the resistance component. Phase angle used the average values of the left and right legs and the left and right arms. The leg muscle score is an index that expresses the percentage of leg muscle mass to body weight as a score. Upper limb muscle quality is an index of maximum grip strength divided by upper limb muscle mass. For ULMQ, we adopted the mean value of right ULMQ and left upper limb muscle mass quality. Sarcopenia and dynapenia were determined based on the Asian Working Group for Sarcopenia 2019 criteria and report by Chen *et al.*[17] and Yamada *et al.*[18] A condition in which only SMI decreased was defined as presarcopenia. However, SMI and muscle strength and/or physical capacity are defined as sarcopenia. Skeletal muscle mass index is normal, but muscle strength and/or physical ability are decreased in dynapenia. Muscle strength is assessed normal with grip strength of at least 28 kg for males and 18 kg for females.[17] Physical ability is normal with a walking speed of at least 1.0 m/s.[17] Muscle mass was determined to be normal with SMI using BIA of at least 7.0 kg/m^2 in males and 5.7 kg/m^2 in females.[17]

Statistical analysis. All statistical data were analyzed using EZR ver. 1.54 (Saitama Medical Center, Jichi Medical University, Saitama, Japan).[22] Age, height, walking speed, maximum grip strength, body weight, BMI, muscle mass, SMI, appendicular skeletal mass (ASM), body fat mass, basal metabolic rate, total body water mass, bone mass, ULMQ, phase angle, and leg muscle score are expressed as mean ± SD. Nominal variables are presented as number of cases and frequency (%) for each item. The Smirnov–Grubbs test was used to test for outliers. The two groups were compared using the Mann–Whitney *U* test for continuous variables and χ^2 test (including Yates continuity correction) for nominal variables. The Fisher's exact test was used as the nominal variable for the four groups. Additionally, to avoid the problem of multiple comparisons, corrections were made using the Bonferroni method. Dependent variable was the presence or absence of dynapenia, and independent variables were ULMQ and knee OA based on medical evidence for the purpose of this study. Multiple logistic regression analysis (binomial logistic regression analysis) was performed, considering age and sex as adjustment variables, and independent factors of dynapenia were analyzed. Additionally, receiver operating characteristics (ROC) curves were generated for the independent factors identified using binomial logistic regression analysis to examine their clinical relevance, and the area under the curve (AUC) was used to determine the fit of the regression model. The goodness-of-fit of the regression model was determined using the AUC. Cut-off values for the ULMQ and phase angle (upper and lower limbs) in the presence and absence of dynapenia were confirmed using the ROC analysis. In any case, $p<0.05$ was considered statistically significant.

Results

Comparison of robust and dynapenia backgrounds. Results from 433 older individuals (129 men and 304 women) in Wakasa town showed that 363 were normal and 67 (15.4%) had dynapenia. Comparison of both groups is shown in Table 1. Significant differences between the groups were age, female sex, alcohol consumption, dyslipidemia, hypertension, rheumatic disorders, spine disease, knee OA, height, walking speed, maximum grip strength, body weight, muscle mass, SMI, ASM, basal metabolic rate, total body water mass, bone mass, ULMQ, phase angles of the upper and lower limbs, and leg muscle score (Table 1).

Comparison of robust and dynapenia backgrounds according to sex. Twelve of the 129 (9.3%) males had dynapenia. Comparisons in robust and dynapenia in males are shown in Table 2. Significant differences in age, knee OA, herniated disc, height, walking speed, maximum grip strength, muscle mass, ASM, BMR, bone mass, ULMQ, phase angle of the lower limb, and leg muscle score were found between the two groups (Table 2). Fifty-five of the 304 females (18.0%) had dynapenia. Comparisons in robust and dynapenia in females are shown in Table 2. Significant differences age, smoking, dyslipidemia, rheumatism, knee OA, height, walking speed, maximum grip strength, body weight, muscle mass, SMI, ASM, BMR, total body water mass, bone mass, ULMQ, phase angle of the lower limb, and leg muscle score were found between the two groups (Table 2).

Independent factor and clinical relevance associated with dynapenia. The independent factors of dynapenia were age [odds ratio (OR): 1.18, 95% confidence interval (CI): 1.110–1.250, $p<0.001$], ULMQ (OR: 0.33, 95% CI: 0.243–0.459, $p<0.001$), and knee OA (OR: 4.06, 95% CI: 1.490–11.100, $p = 0.006$) (Table 3). Receiver operating characteristic curve analysis of clinical relevance showed an AUC of 0.9 (95% CI:

doi: 10.3164/jcbn.24-58

Table 1. Comparison of robust and dynapenia backgrounds

	Total $n = 433$	Dynapenia $n = 67$ (15.4)	Robust $n = 366$ (84.5)	p value
Age (years)	76.0 ± 7.1	82.7 ± 6.1	74.8 ± 6.6	<0.001
Female sex, *n* (%)	304 (70.2)	55 (82.1)	249 (68.0)	0.02
Lifestyle				
Smoking, *n* (%)	22 (5.0)	4 (6.0)	18 (4.9)	0.761
Alcohol consumption, *n* (%)	130 (30.0)	11 (16.4)	119 (32.5)	0.009
Underlying disease				
Diabetes mellitus, *n* (%)	52 (12.0)	10 (14.9)	42 (11.5)	0.416
Cardiac disease, *n* (%)	69 (15.9)	13 (19.4)	56 (15.3)	0.467
Dyslipidemia, *n* (%)	142 (32.7)	13 (19.4)	129 (35.2)	0.011
Hypertension, *n* (%)	231 (53.3)	44 (65.7)	187 (51.1)	0.033
Rheumatism, *n* (%)	9 (2.0)	5 (7.5)	4 (1.1)	0.006
Spinal disease, *n* (%)	55 (12.7)	15 (22.4)	40 (10.9)	0.015
Knee osteoarthritis, *n* (%)	32 (7.3)	14 (20.9)	18 (4.9)	<0.001
Herniated disc, *n* (%)	12 (2.7)	4 (6.0)	8 (2.2)	0.098
Osteoporosis, *n* (%)	70 (16.1)	16 (23.9)	54 (14.8)	0.071
Anthropometry and physical function				
Height (cm)	153.7 ± 9.2	147.6 ± 7.8	154.8 ± 9.1	<0.001
Walking speed (m/s)	1.5 ± 0.4	0.94 ± 0.33	1.62 ± 0.33	<0.001
Maximum grip strength (kg)	28.7 ± 8.6	20.2 ± 6.0	30.2 ± 8.1	<0.001
Body composition analyzer				
Body weight (kg)	55.1 ± 10.0	50.9 ± 8.8	55.9 ± 10.1	<0.001
BMI (kg/m^2)	23.1 ± 3.0	23.2 ± 2.9	23.1 ± 3.0	0.924
Muscle mass (kg)	37.3 ± 7.5	33.5 ± 5.8	38.0 ± 7.6	<0.001
SMI (kg/m^2)	6.8 ± 0.9	6.5 ± 0.7	6.9 ± 0.9	<0.001
ASM (kg)	16.4 ± 3.9	14.4 ± 2.9	16.8 ± 3.9	<0.001
Body fat mass (kg)	15.6 ± 5.6	15.5 ± 6.1	15.6 ± 5.6	0.519
BMR (kcal)	1,105.0 ± 197.7	998.3 ± 151.2	1,124.5 ± 199.2	<0.001
Total body water mass (kg)	28.9 ± 5.2	26.5 ± 4.1	29.3 ± 5.3	<0.001
Total fat index	6.6 ± 2.5	7.1 ± 2.8	6.5 ± 2.4	0.218
Limb fat index	2.9 ± 0.9	3.1 ± 1.0	2.9 ± 0.9	0.227
Bone mass (kg)	2.1 ± 0.4	1.8 ± 0.3	2.1 ± 0.4	<0.001
Upper limb muscle quality (kg/kg)	15.0 ± 1.4	13.4 ± 1.5	15.3 ± 1.1	<0.001
Phase angle of upper limb (°)	5.5 ± 0.7	5.3 ± 0.7	5.5 ± 0.6	0.002
Phase angle of lower limb (°)	4.2 ± 0.9	3.4 ± 0.7	4.4 ± 0.8	<0.001
Leg muscle score (points)	87.5 ± 9.1	83.2 ± 7.9	88.3 ± 9.1	<0.001

n (%); mean ± SD (unit); BMI, body mass index; BMR, basal metabolic rate; SMI, skeletal muscle mass index; ASM, appendicular skeletal muscle mass; continuous variables, Mann–Whitney *U* test; nominal variables, χ^2 test (including Yates continuity correction).

0.856–0.943) (Table 3).

Independent factors and clinical associations with dynapenia according to sex. The independent factors of dynapenia for males were age (OR: 1.12, 95% CI: 1.000–1.260, $p = 0.046$), ULMQ (OR: 0.39, 95% CI: 0.202–0.783, $p = 0.007$) (Table 4). Receiver operating characteristic curve analysis of clinical relevance showed an AUC of 0.841 (95% CI: 0.703–0.979) (Table 4). The independent factors of dynapenia for females were age (OR: 1.20, 95% CI: 1.110–1.300, $p<0.001$), ULMQ (OR: 0.30, 95% CI: 0.211–0.447, $p<0.001$), and knee OA (OR: 3.41, 95% CI: 1.110–10.400, $p = 0.003$) (Table 4). Receiver operating characteristic curve analysis of clinical relevance showed an AUC of 0.9 (95% CI: 0.856–0.943) (Table 4).

Comparative analysis of OA of the knee and four groups (robust, dynapenia, presarcopenia, and sarcopenia). Knee OA had the highest complication rate with dynapenia: 18 of 366 (4.9%) with robust, 67 (20.9%) with dynapenia, 3 of 86 (3.5%) with presarcopenia, and 4 of 45 (8.9%) with sarcopenia. Comparison of the four groups showed significant overall differences ($p<0.001$) (Table 5). Multiple analysis showed significant differences between robust and dynapenia ($p<0.001$) and dynapenia and presarcopenia ($p = 0.007$) (Table 5).

ULMQ cut-off values in the presence and absence of dynapenia. Receiver operating characteristic curve analysis of the relationship between dynapenia and ULMQ revealed an AUC of 0.806 (95% CI: 0.658–0.953), with a cut-off value of 14.3 kg/kg, sensitivity of 75%, and specificity of 78% in men. In women, the AUC was 0.849 (95% CI: 0.858–0.968), cut-off value was 14.0 kg/kg, sensitivity was 65%, and specificity was 90% (Table 6 and Fig. 1). In the ROC analysis of phase angle with dynapenia in men, the AUC was 0.615 (95% CI: 0.429–0.800), with a cut-off value of 5.7, sensitivity of 66%, and specificity of 62%, and without dynapenia, the AUC was 0.583 (95% CI: 0.498–0.668), with a cut-off value of 5.2, sensitivity of 63%, and specificity of 55% (Table 6). The phase angle of the lower limb in men showed an AUC of 0.766 (95% CI: 0.595–0.937),

Table 2. Comparison of robust and dynapenia backgrounds according to sex

	Male participants				Female participants			
	Total *n* = 129	Dynapenia *n* = 12 (9.3)	Robust *n* = 117 (90.6)	*p* value	Total *n* = 304	Dynapenia *n* = 55 (18.0)	Robust *n* = 249 (81.9)	*p* value
Age (years)	75.0 ± 7.0	82.3 ± 7.9	74.3 ± 6.6	0.001	76.4 ± 7.1	82.8 ± 5.8	75.0 ± 6.6	<0.001
Lifestyle								
Smoking, *n* (%)	19 (14.7)	1 (8.3)	18 (15.4)	0.819	3 (0.9)	3 (5.5)	0 (0.0)	0.003
Alcohol consumption, *n* (%)	91 (70.5)	7 (58.3)	84 (71.8)	0.521	39 (12.8)	4 (7.3)	35 (14.1)	0.255
Underlying disease								
Diabetes mellitus, *n* (%)	19 (14.7)	2 (16.7)	17 (14.5)	1	33 (10.8)	8 (14.5)	25 (10.0)	0.464
Cardiac disease, *n* (%)	25 (19.3)	2 (16.7)	23 (19.7)	1	44 (14.4)	11 (20.0)	33 (13.3)	0.282
Dyslipidemia, *n* (%)	36 (27.9)	1 (8.3)	35 (29.9)	0.212	106 (34.8)	12 (21.8)	94 (37.8)	0.037
Hypertension, *n* (%)	75 (58.1)	10 (83.3)	65 (55.6)	0.121	156 (51.3)	122 (49.0)	34 (61.8)	0.116
Rheumatism, *n* (%)	0 (0)	0 (0)	0 (0)	—	9 (2.9)	5 (9.1)	4 (1.6)	0.012
Spinal disease, *n* (%)	10 (7.7)	1 (8.3)	9 (7.7)	1	45 (14.8)	14 (25.5)	31 (12.4)	0.02
Knee osteoarthritis, *n* (%)	4 (3.1)	2 (16.7)	2 (1.7)	0.049	28 (9.2)	12 (21.8)	16 (6.4)	0.001
Herniated disc, *n* (%)	3 (2.3)	2 (16.7)	1 (0.9)	0.014	9 (2.9)	2 (3.6)	7 (2.8)	1
Osteoporosis, *n* (%)	1 (0.7)	0 (0.0)	1 (0.9)	1	69 (22.7)	16 (29.1)	53 (21.3)	0.283
Anthropometry and physical function								
Height (cm)	164.3 ± 6.2	158.7 ± 3.8	164.9 ± 6.1	0.001	149.2 ± 6.1	145.1 ± 6.1	150.1 ± 5.8	<0.001
Walking speed (m/s)	1.62 ± 0.38	1.09 ± 0.36	1.68 ± 0.35	<0.001	1.47 ± 0.41	0.91 ± 0.31	1.60 ± 0.33	<0.001
Maximum grip strength (kg)	38.6 ± 6.9	28.5 ± 6.0	39.7 ± 6.1	<0.001	24.4 ± 5.0	18.3 ± 4.2	25.8 ± 4.1	<0.001
Body composition analyzer								
Body weight (kg)	65.2 ± 8.3	61.8 ± 5.2	65.6 ± 8.5	0.108	50.8 ± 7.3	48.5 ± 7.5	51.3 ± 7.1	0.005
BMI (kg/m^2)	24.1 ± 2.5	24.5 ± 1.4	24.1 ± 2.6	0.246	22.7 ± 3.0	23.0 ± 3.1	22.7 ± 3.0	0.762
Muscle mass (kg)	7.6 ± 4.2	44.7 ± 3.4	47.9 ± 4.2	0.009	32.9 ± 3.0	31.0 ± 2.3	33.4 ± 3.0	<0.001
SMI (kg/m^2)	7.92 ± 0.65	7.81 ± 0.52	7.94 ± 0.67	0.621	6.43 ± 0.56	6.28 ± 0.45	6.47 ± 0.58	0.01
ASM (kg)	21.4 ± 2.7	19.7 ± 1.8	21.6 ± 2.7	0.018	14.3 ± 1.9	13.2 ± 1.6	14.6 ± 1.9	<0.001
Body fat mass (kg)	15.0 ± 5.5	14.6 ± 3.6	15.0 ± 5.7	0.948	15.8 ± 5.7	15.6 ± 6.5	15.9 ± 5.5	0.393
BMR (kcal)	1,355.3 ± 135.0	1,263.1 ± 103.4	1,364.8 ± 134.6	0.009	998.7 ± 100.2	940.6 ± 82.3	1,011.6 ± 99.4	<0.001
Total body water mass (kg)	35.5 ± 3.5	34.0 ± 3.2	35.7 ± 3.5	0.122	26.0 ± 2.7	24.8 ± 1.9	26.3 ± 2.7	<0.001
Total fat index	4.5 ± 1.6	4.6 ± 1.1	4.5 ± 1.7	0.65	5.3 ± 1.9	5.3 ± 2.2	5.3 ± 1.8	0.75
Limb fat index	1.8 ± 0.5	1.8 ± 0.3	1.8 ± 0.5	0.721	2.4 ± 0.6	2.3 ± 0.8	2.4 ± 0.6	0.463
Bone mass (kg)	2.6 ± 0.2	2.4 ± 0.1	2.6 ± 0.2	0.009	1.8 ± 0.2	1.7 ± 0.2	1.9 ± 0.2	<0.001
Upper limb muscle quality (kg/kg)	14.9 ± 1.2	13.5 ± 1.3	15.1 ± 1.1	0.001	15.0 ± 1.4	13.4 ± 1.5	15.4 ± 1.1	<0.001
Phase angle of upper limb (°)	6.0 ± 0.6	5.83 ± 0.60	6.04 ± 0.6	0.192	5.2 ± 0.6	5.2 ± 0.7	5.3 ± 0.6	0.053
Phase angle of lower limb (°)	4.6 ± 0.7	3.9 ± 0.9	4.7 ± 0.6	0.002	4.0 ± 0.9	3.3 ± 0.6	4.2 ± 0.9	<0.001
Leg muscle score (points)	85.5 ± 7.1	80.2 ± 7.2	86.0 ± 6.9	0.01	88.3 ± 9.7	83.8 ± 8.0	89.3 ± 9.8	<0.001

n (%); mean ± SD (unit); BMI, body mass index; BMR, basal metabolic rate; SMI, skeletal muscle mass index; ASM, appendicular skeletal muscle mass; continuous variables, Mann–Whitney *U* test; nominal variables, χ^2 test (including Yates continuity correction).

Table 3. Independent factors and their clinical relevance associated with dynapenia

	Odds ratio	95% CI lower–upper	*p* value	ROC	
				Area under the curve	95% CI lower–upper
Age	1.18	1.110–1.250	<0.001	0.9	0.856–0.943
Sex (female)	2.21	0.940–5.180	0.069		
Upper limb muscle quality	0.33	0.243–0.459	<0.001		
Knee osteoarthritis	4.06	1.490–11.100	0.006		

Multiple logistic regression analysis (binomial logistic regression analysis); CI, confidence interval; OR, odds ratio. Receiver operating characteristic (ROC) curves were generated for risk factors identified using binomial logistic regression analysis to examine their clinical relevance, and the area under the curve (AUC) was used to determine the regression model fit.

with a cut-off value of 4.2, sensitivity of 66%, and specificity of 76%, and in women, the AUC was 0.805 (95% CI: 0.741–0.870), with a cut-off value of 3.7, sensitivity of 70%, and specificity of 75% (Table 6).

Discussion

In this study, age, ULMQ, and knee OA were shown to be clinically valid independent factors for dynapenia. Furthermore,

doi: 10.3164/jcbn.24-58

Table 4. Independent factors associated with dynapenia according to sex and clinical relevance

	Male participants					Female participants				
	OR	95% CI lower–upper	*p* value	ROC		OR	95% CI lower–upper	*p* value	ROC	
				Area under the curve	95% CI lower–upper				Area under the curve	95% CI lower–upper
Age	1.12	1.000–1.260	0.046			1.2	1.110–1.300	<0.001		
Upper limb muscle quality	0.39	0.202–0.783	0.007	0.841	0.703–0.979	0.3	0.211–0.447	<0.001	0.911	0.867–0.955
Knee osteoarthritis	13.3	0.968–182.000	0.052			3.41	1.110–10.400	0.003		

Multiple logistic regression analysis (binomial logistic regression analysis); CI, confidence interval; OR, odds ratio. Receiver operating characteristic (ROC) curves were generated for the risk factors identified using binomial logistic regression analysis to examine their clinical relevance, and the area under the curve (AUC) was used to determine the regression model fit.

Table 5. Comparative analysis of knee osteoarthritis and four groups (robust, dynapenia, presarcopenia, and sarcopenia)

	Robust[a] *n* = 366	Dynapenia[b] *n* = 67	Pre-Sarcopenia[c] *n* = 86	Sarcopnia[d] *n* = 45	a vs b *p* value	a vs c *p* value	a vs d *p* value	c vs d *p* value	b vs c *p* value	b vs d *p* value	*p* value
Knee osteoarthritis, *n* (%)	18 (4.9)	14 (20.9)	3 (3.5)	4 (8.9)	<0.001	1.000	1.000	1.000	0.007	0.704	<0.001

n (%), nominal variables Fisher's exact test (multiple comparisons of two groups at a time with Bonferroni adjustment).

Table 6. Upper limb muscle quality cut-off values in the presence and absence of dynapenia

	Sex	AUC	95% CI lower–upper	Sensitivity	Specificity	Cut-off value
Upper limb muscle quality (Grip strength/muscle mass)	Male	0.806	0.658–0.953	75%	78%	14.3 kg/kg
	Female	0.849	0.786–0.912	65%	90%	14.0 kg/kg
Phase angle (upper limb)	Male	0.615	0.429–0.800	66%	62%	5.7°
	Female	0.583	0.498–0.668	63%	55%	5.2°
Phase angle (lower limbs)	Male	0.766	0.595–0.937	66%	76%	4.2°
	Female	0.805	0.741–0.870	70%	75%	3.7°

AUC, area under the curve; CI, confidence interval.

examination of cut-off values using ROC analysis revealed that ULMQ showed good accuracy in predicting dynapenia, while simultaneously indicating the best cut-off value for ULMQ. Factors that differ significantly in the comparison of dynapenia and robust by sex were different, with clinically valid independent factors for dynapenia being age and ULMQ in males and age, ULMQ, and knee OA in females. We found that females have about twice as much dynapenia as males. Additionally, we found that dynapenia was more than twice as likely to be complicated by knee OA than robust, presarcopenia, or sarcopenia.

Knee OA and OA have been found to correlate with decreased grip strength.[16,23] In contrast, Kim *et al.*[24] reported that muscle weakness in a dynapenia group was susceptible to aging. From the outset, it has been proposed that there is another mechanism underlying dynapenia than sarcopenia (contractile properties and altered neural function), and it has been strongly advocated that attention should be paid to numerous factors when determining dynapenia.[10] In this study, we focused on ULMQ and knee OA. Osteoarthritis has been classified as non-inflammatory arthritis, but as numerous immune processes are recognized within the joints and synovium, the clear distinction between inflammatory and degenerative arthritis is disappearing.[25] The symptoms of OA are characterized by mild, systemic, low-grade inflammation rather than severe inflammation.[26] In patients with knee OA, increased muscle proinflammatory mediators were found to be correlated with altered knee function, increased disability, and decreased row speed during walking.[27] Inflammation is also an important factor in skeletal muscle atrophy.[28] Inflammation caused by OA may contribute to dynapenia by decreasing muscle strength and quality. Patients with OA are known to have a marked increase in the adipocyte factor, leptin, which is involved in metabolic and immune regulation.[29] The higher the leptin concentration, the higher the risk of physical dysfunction.[30] Higher leptin levels decrease the risk of sarcopenia, but increase the risk of dynapenia in the older individuals.[31] The OA-leptin-dynapenia pathway is one of the most promising hypotheses for OA and dynapenia. Additionally, the analysis of independent factors according to sex showed knee OA in women, but only a trend in men. This may be because the number of male participants was smaller than that of females. It can also be inferred that women's susceptibility to knee OA[32] was also an independent factor for dynapenia. Additionally, from this study, dynapenia is associated with a higher rate of knee OA than sarcopenia or presarcopenia, and we can speculate on the involvement of arthritis as a mechanism that differs from sarcopenia.

Evidence suggests that dynapenia (loss of muscle mass), which differs from sarcopenia (loss of muscle mass), may be more influential in the decline of health in old age, with loss of muscle mass and muscle strength following different pathways.[33] It is also necessary to recognize the concept of muscle quality.[33] It is

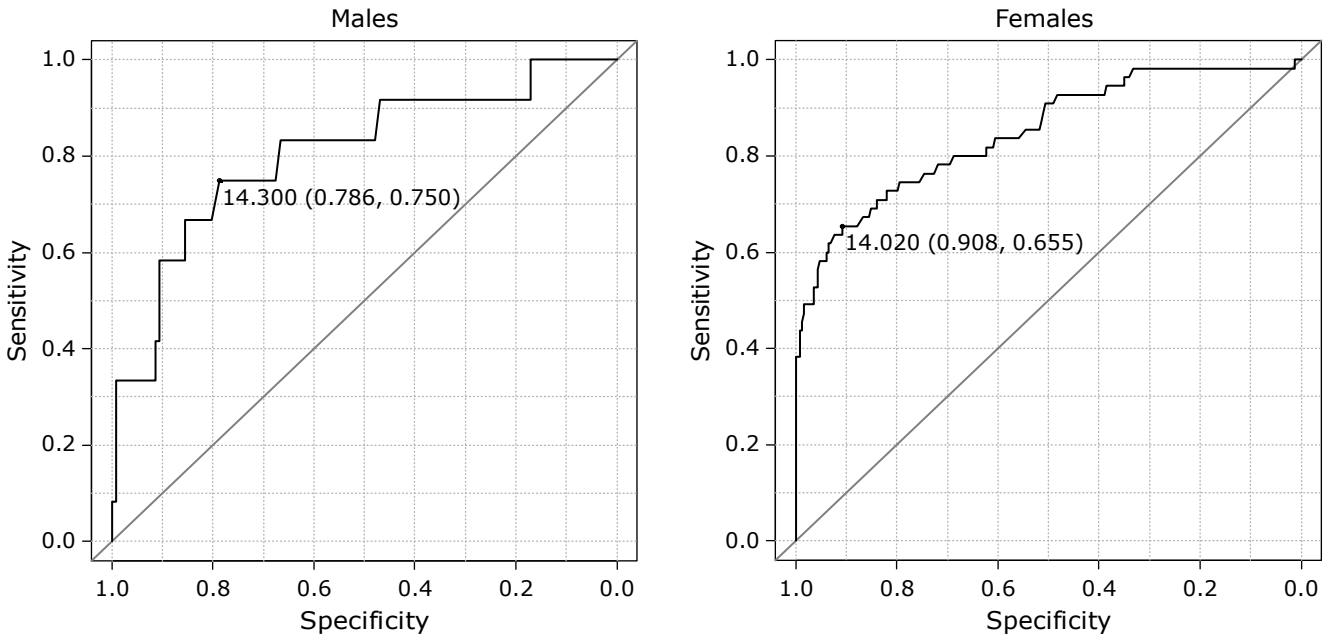

Fig. 1. Cut-off according to upper extremity muscle quality in the presence or absence of dynapenia. Area under the curve. In men: Area under the curve, 0.806 (95% confidence interval: 0.658–0.953); sensitivity, 75%; specificity, 75%; and cut-off value, 14.3 kg/kg. In women: Area under the curve, 0.849 (95% confidence interval: 0.786–0.912); sensitivity, 65%; specificity, 90%; and cut-off value, 14.0 kg/kg.

possible that the indices observed in the sarcopenia and dynapenia assessment methods differed. The ULMQ calculates the results using the maximum grip strength value; however, it is possible that the muscle fibers used for grip strength are different from those used for calculating walking speed. Muscle fibers are classified into two types: slow muscle fibers (type 1 fibers), which converge slowly, but have high metabolic capacity and strength and are not easily fatigued; and fast muscle fibers (type 2 fibers), which have excellent instantaneous force, but are easily fatigued. One of the characteristics of movements in older individuals is slower movement and weaker muscles, which may be related to age-related decrease in type 2 fibers. Many studies have reported that muscle fiber size in older individuals is greatly reduced at the myocyte level.[34–36] In contrast, the type 1 muscle fiber size is largely maintained with aging.[35,37,38] The concept of dynapenia does not evaluate the loss of skeletal muscle mass as in the concept of sarcopenia, but rather the loss of muscle quality without the loss of skeletal muscle mass. That is, they assess the decline in muscle quality. We use maximal grip strength to assess muscle quality, but type 2 fibers are observed to excel in instantaneous force. Thus, our results predict that sarcopenia evaluates type 1 fibers and dynapenia evaluates type 2 fibers. The results of this study confirm those of previous studies using knee OA and ULMQ, which have a significant partial correlation with dynapenia. In contrast, the cut-off values, sensitivity, and specificity of dynapenia and ULMQ for both men and women showed higher affinities than phase angle. These findings suggest that dynapenia differs from sarcopenia in the observed muscle fibers, with type 2 fibers observed and reflected in the ULMQ. The accuracy of the quality of the upper limb muscles in the determination of dynapenia could also be attributed to the fact that grip strength was considered.

This study has several limitations. First, we conducted a cross-sectional study, which does not allow us to infer causal relationships. Second, our data are limited to older adults living in a limited geographic area, which may limit the generalizability of our findings. Therefore, we aim to conduct similar studies in older adults residing in different geographic areas to allow generalization of our findings. Third, hand impairments may make it impossible to measure grip strength (e.g., advanced arthritis or stroke). Fourth, the *in vivo* metabolic mechanisms related to the ULMQ and knee OA in dynapenia are currently unknown and require further investigation in future studies.

In this study, which examined the methods for evaluating dynapenia using the ULMQ, age, ULMQ, and knee OA were found to be independent factors for dynapenia. Furthermore, we demonstrated that the ULMQ (grip strength/upper limb muscle mass) had good accuracy in detecting dynapenia in both men and women. The cut-off values for ULMQ to predict dynapenia were 14.3 kg for older men and 14.0 kg for older women. Assessment of ULMQ may contribute to simplifying the diagnosis of dynapenia.

Author Contributions

OY and HO contributed significantly to the conceptualization of the study; TK, HO, HT, YM, RI, TT, HH, and OY contributed significantly to data acquisition; TK, HO, KK, and OY contributed significantly to data analysis and interpretation; and TK, HO, and OY contributed to manuscript preparation. All authors critically reviewed and revised the manuscript, and approved and submitted the final version.

Acknowledgments

This study was conducted in cooperation with medical staff (doctors, nurses, public health nurses, radiological technologists, dieticians, occupational therapists, physical therapists, and clinical laboratory technologists), office workers, and students, as well as the Wakasa Town Office and Fukui Dietetic Association. We would like to express our gratitude to them. We are also grateful to Yuka Nakamura, Mie Yamashita, Noriko Sadakane, and Satoko Hirose for their assistance with office work and preparations. We thank Enago (www.enago.jp) for the English language editing.

Indicate the affiliations of the people who collaborated on the study.

doi: 10.3164/jcbn.24-58

University of Fukui, Jin-ai University, Kitasato Junior College of Health Hygienic Sciences, Kinjo University, Niigata University of Health and Welfare, Kanazawa University, University of Fukui Hospital, Fukui Kosei Hospital, Fukui Ken Saiseikai Hospital, Fukui Prefectural Hospital, Harue Hospital, Nakamura Hospital, National Hospital Organization Kanazawa Medical Center, National Hospital Organization Tsuruga Medical Center, Anamizu General Hospital, Sugita Genpaku Memorial Obama Municipal Hospital, Wada Community Clinic, JCHO Wakasa Takahama Hospital, Obama City Kado Elementary School, and Sakai Municipal Mikuni Hospital, Fukui Prefecture (Health and Welfare) collaborated in this study.

Funding

This study was funded by the Japan Society for the Promotion of Science through the JSPS KAKENHI Grant-in-Aid for Scientific Research Project/Basic Research (C) under Grant Number 20K10399.

Conflict of Interest

No potential conflicts of interest were disclosed.

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doi: 10.3164/jcbn.24-58