new device, we have proposed new indices and showed the difference by sex or hand side.[19]

In the present study, using the data from our newly-developed device, we investigated the association of gripping performance and independence of ADL in older adults, evaluated by total Barthel Index (BI) score and its subitems, and attempted to reveal the meaning of the newly proposed indices, as well as that of maximum grip strength.

Methods

Study population

The participants of the present analyses were recruited at the outpatient clinic for memory disorders at the National Center for Geriatrics and Gerontology, Japan at Obu City, Aichi Prefecture in Japan. The period of recruitment was from 18 October 2010 to 10 June 2011. Inclusion criteria were principally the patients who visited our memory disorder clinic for the first time and could understand the instructions on how to measure grip strength with the new device. Before the examination, their blood pressure was measured, and those with higher than 160 mmHg systolic pressure were excluded. The participants of the present study were 347 patients (142 men and 205 women, average age 75.0 ± 9.1 years).

Average Mini-Mental State Examination (MMSE) score was 21.1 ± 6.1 in men and 20. 2 ± 5.7 in women.

Evaluations of ADL independence by BI and participant grouping

Independence of the ADL was evaluated by BI[20] questionnaire. The index is composed of 10 items regarding bathing, grooming, feeding, dressing, toilet use, ascend/descend stairs, bowel management, bladder management, bed/wheelchair transfer and mobility (level surface), totaling 100 points as a full score. Participants were classified into two groups based on the total BI score. Those with a total score of 100 points were classified as independent, and those with less than 100 points as dependent. They were also classified by the scores on each of the 10 component subitems of BI (full score, less than full score).

Newly-developed device for measuring grip strength

Using the force-gauge (manufactured by IMADA, Toyohashi, Japan; product no. ZP-500N) for measuring industrial products, the signal output from the device is sent to a computer (Fig. 1). At the moment an LED lamp on the device lights up, the examinee is encouraged to grip the handle, and the grip strength is constantly recorded by the computer. How the gripping strength is produced can be automatically described on

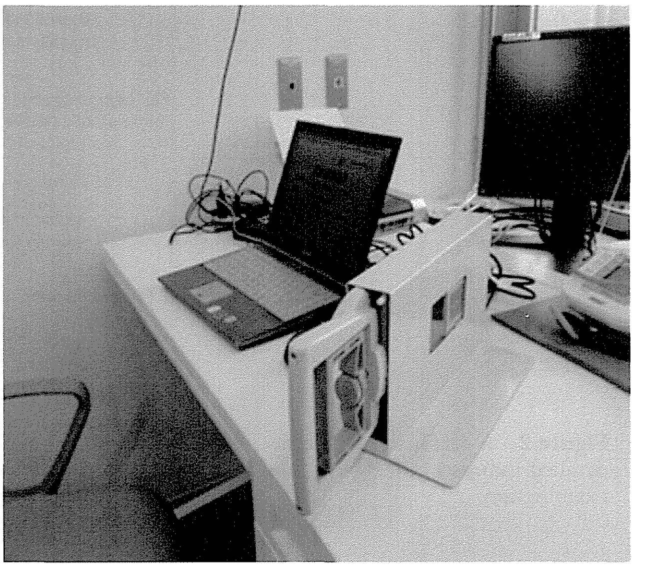

Figure 1 Newly-developed device for measuring grip strength. Force-gauge (made by IMADA, Toyohashi, Japan) can be used for measuring industrial products, such as the operation switch on a deluxe automobile. The gauge is equipped with an easy-grip handle. The signal output from the device is sent to the computer. The moment the LED lamp on the device lights up, the examinee grips the handle. Grip strength is constantly recorded by the computer. How the gripping strength is produced is automatically described on the computer monitor.

the computer monitor. Not only can it measure the maximum (peak) grip strength accurately, even very low levels of strength, but it can also measure the response time, agility (catching ability) or endurance (holding ability).

Method for measuring grip strength and items calculated

The participants were mostly elderly patients, whose grip strength was measured in the sitting position, with their elbows flexed approximately 90°. In the agility examination, the examinees were asked to grip the handle as soon as the lamp illuminated. The time and the pattern to reach the peak value were then evaluated.

For the analyses to assess agility in detail, from the graph showing the data output and recorded on the computer monitor, we selected four points: (i) lamp lights up; (ii) time to start gripping; (iii) turning point when curve inclination changes; and (iv) peak. We then defined nine indices, calculated with these four points as follows: (1) maximum strength; (2) response time; (3) time to reach maximum strength; (4) time to reach turning point; (5) strength at turning point; (6) inclination from start to turning point; (7) time from turning point to reach maximum strength; (8) inclination from turning point to maximum strength; and (9) ratio of strength (turning point/maximum); (Fig. 2).

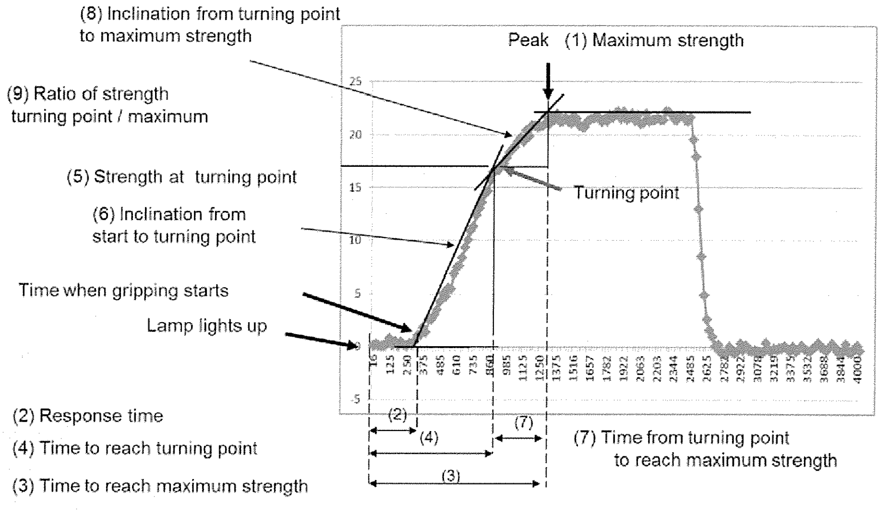

Figure 2 A graph showing nine detailed indices in the agility examination.

Statistical analyses

The average maximum grip strength was compared between the independent group and dependent group (both BI total score and each subclass item). Also, the average absolute values of each of the aforementioned nine items were calculated, and then the relationships were investigated between those items and BI scores of the total, and that of each subclass: bathing, grooming, feeding, dressing, toilet use, ascend/descend stairs, bowel management, bladder management, bed/wheelchair transfer and mobility were investigated with Pearson's coefficient, utilizing SPSS version 19 for Windows (SPSS, Chicago, IL, USA) was used. Partial correlations adjusted for age and total score of MMSE were also examined. Furthermore, the relationships between the nine grip strength measuring items and total BI scores of the three different age groups, below 70 years, 70s and 80s, were also investigated with partial Pearson's coefficient, adjusted for MMSE. *P*-values less than 0.05 were considered statistically significant. The study protocol was approved by the Committee on Ethics of Human Research of the National Institute for Longevity Sciences. Written informed consent was obtained from each participant.

Results

Participant characteristics

The demographic data of participants are listed in Table 1. There were significant differences between the independent group and dependent group in age, height, weight, and BI score (both total and each subclass item) in both sexes. Significant differences were seen in five of the nine newly advocated indices with the right hand in men, and in seven of the nine items in women. Significant differences were seen only in women regarding two indices: time to reach maximum strength and ratio of strength (turning point/maximum).

Comparisons of maximum grip strength

The partial correlation coefficients between the maximum grip strength and BI total score, after adjusting age and sex, were 0.296 for the right hand ($P < 0.001$) and 0.295 for the left hand ($P < 0.001$), showing significant relationships. Even after adjusting for MMSE total score, they were 0.228 for the right hand ($P < 0.001$) and 0.238 for the left hand ($P < 0.001$), and the relationships remained significant.

Comparisons among groups divided in terms of scores for total BI and each of the 10 subclass items in men showed significant differences between the full score (independent) group and those losing points (dependent) in total BI and all subitems. Similarly in women, except in one item of feeding, significant differences were shown between the independent and dependent group for almost all subitems, as well as for total BI (Table 2).

Correlations between nine grip strength items measured and BI

Partial correlations between the nine grip strength items measured and BI score (total score and each of 10 subitems), adjusted for age and MMSE, were examined for both hands in men (Table 3) and in women (Table 4). In men, maximum grip strength was significantly correlated with eight items in the left hand and five in the right, as well as with the total score in both hands. Response time was significantly correlated with five items in the left hand, four in the right hand and total score in both hands. Time to voach turning point was significantly correlared with five items and with total score in the left hand. Strength at turning point was significantly correlated with four items in the left hand

Table 1 General characteristics of participants

	Men	Independent (n = 87)	Dependent (n = 55)	P-value		Women	Independent (n = 144)	Dependent (n = 61)	P-value
	Age (years)	72.6 ± 8.7	75.5 ± 10.5	0.073		Age (years)	74.2 ± 8.8	80.1 ± 6.6	<0.001
	Height (cm)	163.9 ± 5.7	160.2 ± 7.2	0.001		Height (cm)	149.8 ± 6.4	144.6 ± 7.1	<0.001
	Weight (kg)	61.2 ± 8.8	57.1 ± 11.2	0.017		Weight (kg)	47.9 ± 8.2	46.1 ± 9.1	0.154
	BMI (kg/m^2)	22.8 ± 2.9	22.1 ± 3.2	0.209		BMI (kg/m^2)	21.3 ± 3.1	22.0 ± 3.8	0.171
	MMSE score	23.0 ± 5.2	18.1 ± 6.3	<0.001		MMSE score	21.4 ± 5.4	17.3 ± 5.5	<0.001
Barthel Index	Total score	100.0 ± 0.0	78.9 ± 21.6	<0.001	Barthel Index	Total score	100.0 ± 0.0	80.7 ± 17.6	<0.001
	Feeding	10.0 ± 0.0	9.4 ± 2.0	0.002		Feeding	10.0 ± 0.0	9.4 ± 1.6	<0.001
	Bed/wheel-chair transfer	15.0 ± 0.0	13.9 ± 2.9	<0.001		Bed/wheel-chair transfer	15.0 ± 0.0	13.9 ± 2.3	<0.001
	Grooming	5.0 ± 0.0	3.8 ± 2.2	<0.001		Grooming	5.0 ± 0.0	3.4 ± 2.4	<0.001
	Toilet use	10.0 ± 0.0	8.3 ± 2.4	<0.001		Toilet use	10.0 ± 0.0	9.1 ± 2.0	<0.001
	Bathing	5.0 ± 0.0	3.5 ± 2.3	<0.001		Bathing	5.0 ± 0.0	2.8 ± 2.5	<0.001
	Mobility	15.0 ± 0.0	13.6 ± 3.7	0.001		Mobility	15.0 ± 0.0	13.8 ± 2.8	<0.001
	Ascend/descend stairs	10.0 ± 0.0	8.5 ± 2.7	<0.001		Ascend/descend stairs	10.0 ± 0.0	8.3 ± 2.9	<0.001
	Dressing	10.0 ± 0.0	8.0 ± 2.8	<0.001		Dressing	10.0 ± 0.0	8.4 ± 2.5	<0.001
	Bowel management	10.0 ± 0.0	6.6 ± 3.0	<0.001		Bowel management	10.0 ± 0.0	6.5 ± 3.0	<0.001
	Bladder management	10.0 ± 0.0	6.2 ± 2.9	<0.001		Bladder management	10.0 ± 0.0	6.2 ± 2.5	<0.001
Nine new indices	Response time (ms)	360.2 ± 153.6	425.6 ± 188.2	0.026	Nine new indices	Response time (ms)	388.6 ± 138.0	492.3 ± 186.7	<0.001
	Time to reach turning point (ms)	692.6 ± 252.2	807.8 ± 304.9	0.016		Time to reach turning point (ms)	761.8 ± 279.4	838.3 ± 273.4	0.077
	Strength at turning point (kg)	24.5 ± 8.3	18.3 ± 7.7	<0.001		Strength at turning point (kg)	16.7 ± 5.8	11.3 ± 4.7	<0.001
	Inclination from start to turning point (kg/ms)	0.082 ± 0.045	0.054 ± 0.037	<0.001		Inclination from start to turning point (kg/ms)	0.048 ± 0.027	0.031 ± 0.017	<0.001
	Time to reach maximum strength (ms)	1276.4 ± 464.6	1302.3 ± 422.1	0.740		Time to reach maximum strength (ms)	1261.2 ± 385.8	1397.4 ± 394.3	0.025
	Maximum strength (kg)	28.3 ± 8.2	21.6 ± 8.8	<0.001		Maximum strength (kg)	19.3 ± 6.0	14.0 ± 5.6	<0.001
	Time from turning point to reach maximum strength (ms)	583.8 ± 403.2	494.5 ± 362.5	0.186		Time from turning point to reach maximum strength (ms)	499.4 ± 331.5	559.2 ± 335.6	0.248
	Ratio of strength (turning point/maximum) (%)	85.7 ± 11.5	84.9 ± 11.3	0.663		Ratio of strength (turning point/maximum) (%)	86.1 ± 10.2	80.9 ± 12.9	0.003
	Inclination from turning point to maximum strength (kg/ms)	0.010 ± 0.010	0.009 ± 0.008	0.451		Inclination from turning point to maximum strength (kg/ms)	0.007 ± 0.005	0.005 ± 0.004	0.119

BMI, body mass index; MMSE, Mini-Mental State Examination.

Table 2 Comparisons of maximum grip strength between independent and dependent groups of total Barthel Index score and each Barthel Index subitem

		Men			Women		
		Independent (*n*)	Dependent (*n*)	*P*-value	Independent (*n*)	Dependent (*n*)	*P*-value
Total score	Right	28.3 ± 8.2 (87)	21.6 ± 8.8 (54)	<0.001	19.3 ± 6.0 (142)	14.0 ± 5.6 (59)	<0.001
	Left	27.3 ± 8.0 (87)	21.1 ± 8.6 (55)	<0.001	17.9 ± 5.7 (143)	12.9 ± 5.4 (60)	<0.001
Feeding	Right	26.3 ± 8.8 (134)	15.4 ± 5.4 (6)	0.003	17.9 ± 6.3 (194)	14.0 ± 4.7 (7)	0.11
	Left	25.4 ± 8.7 (135)	15.9 ± 4.9 (6)	0.009	16.5 ± 6.0 (196)	13.2 ± 6.9 (7)	0.15
Bed/wheelchair transfer	Right	26.3 ± 8.8 (130)	17.5 ± 7.7 (9)	0.004	18.1 ± 6.2 (189)	11.4 ± 5.0 (11)	<0.001
	Left	25.4 ± 8.6 (131)	17.3 ± 8.1 (9)	0.006	16.9 ± 5.9 (190)	10.3 ± 3.9 (12)	<0.001
Grooming	Right	26.8 ± 8.7 (126)	16.1 ± 5.9 (13)	<0.001	18.4 ± 6.2 (181)	12.2 ± 4.3 (20)	<0.001
	Left	25.8 ± 8.3 (127)	15.5 ± 7.0 (13)	<0.001	17.0 ± 6.0 (183)	10.9 ± 3.6 (20)	<0.001
Toilet use	Right	26.9 ± 8.8 (121)	18.4 ± 6.5 (18)	<0.001	18.1 ± 6.3 (190)	12.5 ± 4.5 (10)	0.007
	Left	26.0 ± 8.5 (122)	17.4 ± 6.5 (18)	<0.001	16.8 ± 6.0 (191)	11.4 ± 4.3 (11)	0.004
Bathing	Right	27.0 ± 8.6 (122)	15.7 ± 6.1 (15)	<0.001	18.5 ± 6.1 (175)	12.6 ± 5.1 (25)	<0.001
	Left	26.1 ± 8.3 (123)	14.7 ± 5.6 (15)	<0.001	17.1 ± 5.9 (176)	12.2 ± 5.3 (26)	<0.001
Mobility	Right	26.4 ± 8.8 (131)	16.0 ± 5.6 (8)	0.001	18.0 ± 6.2 (190)	12.8 ± 6.7 (10)	0.01
	Left	25.4 ± 8.6 (132)	16.1 ± 6.3 (8)	0.003	16.7 ± 5.9 (191)	11.7 ± 6.0 (11)	0.006
Ascend/descend stairs	Right	26.8 ± 8.7 (125)	16.9 ± 6.8 (14)	<0.001	18.3 ± 6.2 (183)	12.4 ± 5.0 (17)	<0.001
	Left	25.8 ± 8.4 (126)	16.3 ± 7.1 (14)	<0.001	17.0 ± 5.9 (184)	11.2 ± 4.5 (18)	<0.001
Dressing	Right	26.9 ± 8.6 (121)	17.8 ± 7.7 (18)	<0.001	18.3 ± 6.2 (183)	12.4 ± 4.7 (17)	<0.001
	Left	25.8 ± 8.5 (121)	18.9 ± 8.1 (19)	0.0001	17.0 ± 5.9 (184)	11.0 ± 4.0 (18)	<0.001
Bowel management	Right	27.4 ± 8.3 (108)	20.0 ± 9.1 (32)	<0.001	18.8 ± 6.1 (163)	13.1 ± 5.3 (37)	<0.001
	Left	26.3 ± 8.1 (108)	19.8 ± 9.2 (33)	<0.001	17.5 ± 5.8 (164)	11.8 ± 4.6 (38)	<0.001
Bladder management	Right	27.3 ± 8.7 (104)	20.8 ± 8.3 (35)	<0.001	18.9 ± 6.2 (158)	13.6 ± 5.1 (42)	<0.001
	Left	26.6 ± 8.5 (104)	19.8 ± 7.7 (36)	<0.001	17.6 ± 6.0 (159)	12.4 ± 4.4 (43)	<0.001

Table 3 Partial correlations between nine grip strength items measured and Barthel Index (total score and each sub items) adjusted for age and Mini-Mental State Examination total score in men

			Total score	Feeding	Bed/wheel-chair transfer	Grooming	Toilet use	Bathing	Mobility	Ascend/ descend stairs	Dressing	Bowel management	Bladder management
Response time	Right	*r*	−0.22*	−0.22*	−0.12	−0.10	−0.16	−0.25**	−0.22*	−0.15	−0.19*	−0.14	−0.04
	Left	*r*	−0.24**	−0.29**	−0.16	−0.12	−0.13	−0.27**	−0.23**	−0.18*	−0.25**	−0.06	−0.07
Time to reach turning point	Right	*r*	−0.22*	−0.30**	−0.13	−0.12	−0.13	−0.15	−0.28**	−0.12	−0.12	−0.09	−0.14
	Left	*r*	−0.25**	−0.29**	−0.14	−0.06	−0.15	−0.10	−0.25**	−0.12	−0.20*	−0.19*	−0.18*
Strength at turning point	Right	*r*	0.17	0.12	0.07	0.13	0.10	0.23*	0.10	0.10	0.14	0.16	0.09
	Left	*r*	0.26**	0.15	0.13	0.22*	0.16	0.32**	0.17	0.21*	0.16	0.14	0.18*
Inclination from start to turning point	Right	*r*	0.18*	0.16	0.09	0.12	0.10	0.13	0.15	0.08	0.07	0.11	0.22*
	Left	*r*	0.20*	0.15	0.08	0.16	0.09	0.11	0.16	0.07	0.07	0.20*	0.26**
Time to reach maximum strength	Right	*r*	0.13	−0.10	0.06	0.06	0.14	0.09	0.04	0.12	0.21*	0.14	0.07
	Left	*r*	−0.01	−0.08	0.00	−0.06	0.08	0.11	−0.05	0.02	−0.06	−0.05	0.00
Maximum strength	Right	*r*	0.26**	0.15	0.12	0.18*	0.18*	0.31**	0.16	0.17	0.22*	0.20*	0.16
	Left	*r*	0.30**	0.17	0.15	0.25**	0.23*	0.36**	0.20*	0.23**	0.17*	0.18*	0.23**
Time from turning point to reach maximum strength	Right	*r*	0.30**	0.10	0.17	0.15	0.25**	0.21*	0.24**	0.23*	0.33**	0.22*	0.18*
	Left	*r*	0.15	0.11	0.10	−0.03	0.19*	0.20*	0.10	0.11	0.07	0.07	0.13
Ratio of strength (turning point/maximum)	Right	*r*	−0.22*	−0.07	−0.17	−0.14	−0.20*	−0.19*	−0.20*	−0.17	−0.18*	−0.06	−0.18*
	Left	*r*	−0.09	−0.06	−0.07	−0.02	−0.17*	−0.07	−0.06	0.04	−0.01	−0.12	−0.09
Inclination from turning point to maximum strength	Right	*r*	0.06	0.11	0.09	0.03	0.02	0.12	0.09	0.06	−0.07	−0.04	0.06
	Left	*r*	0.07	0.08	0.08	0.12	−0.06	−0.05	0.09	−0.03	−0.01	0.12	0.10

**$P < 0.01$, *$P < 0.05$.

Table 4 Partial correlations between nine grip strength items measured and Barthel Index (total score and each sub items) adjusted for age and Mini-Mental State Examination total score in women

			Total score	Feeding	Bed/wheel-chair transfer	Grooming	Toilet use	Bathing	Mobility	Ascend/ descend stairs	Dressing	Bowel management	Bladder management
Response time	Right	*r*	−0.14	0.26	−0.05	−0.12	−0.02	−0.16*	0.04	−0.17*	0.07	−0.19*	−0.14
	Left	*r*	−0.16*	−0.10	−0.07	−0.22**	−0.06	−0.16*	0.02	−0.11	0.07	−0.15*	−0.18*
Time to reach turning point	Right	*r*	0.01	0.10	0.10	0.04	0.04	0.03	0.07	−0.03	0.04	−0.12	−0.05
	Left	*r*	0.02	0.03	0.05	−0.07	0.02	0.02	0.09	−0.04	0.08	−0.02	−0.03
Strength at turning point	Right	*r*	0.26**	0.09	0.20**	0.16*	0.11	0.22**	0.12	0.21**	0.15*	0.22**	0.23**
	Left	*r*	0.23**	0.04	0.17*	0.17*	0.09	0.13	0.14	0.15*	0.16*	0.24**	0.25**
Inclination from start to turning point	Right	*r*	0.14	−0.10	0.07	0.02	0.07	0.04	0.10	0.12	0.06	0.20**	0.17*
	Left	*r*	0.11	−0.04	0.09	0.03	0.06	0.02	0.05	0.12	0.03	0.15*	0.16*
Time to reach maximum strength	Right	*r*	−0.11	−0.02	0.04	−0.02	−0.07	−0.01	−0.05	−0.10	−0.08	−0.20**	−0.15*
	Left	*r*	−0.04	0.00	0.01	0.02	−0.05	0.07	−0.02	−0.02	0.01	−0.13	−0.09
Maximum strength	Right	*r*	0.22**	0.06	0.20**	0.15*	0.06	0.19**	0.12	0.17*	0.13	0.18*	0.20**
	Left	*r*	0.23**	0.03	0.19**	0.18*	0.08	0.15*	0.13	0.16*	0.16*	0.19**	0.22**
Time from turning point to reach maximum strength	Right	*r*	−0.14	−0.10	−0.04	−0.06	−0.11	−0.04	−0.11	−0.09	−0.13	−0.12	−0.14
	Left	*r*	−0.06	−0.02	−0.02	0.03	−0.07	0.08	−0.08	−0.01	−0.04	−0.15*	−0.09
Ratio of strength (turning point/maximum)	Right	*r*	0.24**	0.13	0.18*	0.18*	0.25**	0.19**	0.15*	0.18*	0.19*	0.13	0.14
	Left	*r*	0.11	0.08	0.02	−0.01	0.06	−0.04	0.10	0.00	0.09	0.22**	0.17*
Inclination from turning point to maximum strength	Right	*r*	0.04	0.01	−0.01	−0.03	−0.04	−0.02	0.05	0.02	0.01	0.10	0.12
	Left	*r*	0.12	0.02	0.09	0.08	0.07	0.07	0.05	0.08	0.09	0.11	0.12

**$P < 0.01$, *$P < 0.05$.

and with total score. Different from the results before adjustment, in the right hand only one index gained significance. Time from turning point to reach maximum strength and ratio of strength (turning point/maximum strength) were significantly related to seven and five items, respectively, as well as to the total score in the right hand. Inclination from start to turning point was significant only in total score and some subclass items in both hands (Table 3). In women, maximum grip strength was significantly related to seven items in the left hand and six in the right, as well as with the total score in both hands. Response time was significantly related to four items in the left hand and three in the right, whereas the total score was significant only in the left hand. Strength at turning point, differing slightly from men, was significant in seven items in the right hand and six in the left, as well as in the total score in both hands. The ratio of strength (turning point/maximum strength) was significant in seven items and the total score in the right hand (Table 4).

Correlations between nine grip strength items measured and total BI scores in three different age groups

In men aged in their 70s, six out of nine items, namely, response time, time to reach turning point, strength at turning point, maximum grip strength, time from turning point to reach maximum strength and ratio of strength (turning point/maximum), were correlated with total BI score in the right hand, whereas five items, response time, time to reach turning point, strength at turning point, inclination from start to turning point and maximum grip strength, were related with total BI score in the left hand (Table 5). In the age group below 70 years, just two items, strength at turning point and ratio of strength (turning point/maximum), were related in both hands (Table 5). In the 80s age group, no item was correlated in the right hand, and response time and inclination from start to turning point were correlated in the left hand (Table 5).

Much different from men, in women aged in their 70s only one item, strength at turning point, was correlated in the right hand, and also only one item, response time, was correlated in the left (Table 5). In the age group below 70 years, no item was correlated in the right hand, whereas four items, response time, time to reach turning point, time to reach maximum strength and time from turning point to reach maximum strength (all of these were time-related items), showed significant correlations in the left hand. In women aged in their 80s, strength at turning point and maximum strength were correlated in both hands, and time from turning point to reach maximum strength was correlated in the right hand (Table 5).

Discussion

The grip strength test is one of the most popular and widely utilized methods for evaluating muscle strength.[3–5] It is doubtful, however, whether a grip strength device, originally made for young people, is suitable for measuring very weak strength, because average grip strength of female residents (mean age 83.2 years) in a nursing home was reported to be as low as 8.7 kg.[21] We have developed a new grip-strength measuring device that not only measures small values accurately, but also evaluates muscle contraction in detail, by taking a time axis into consideration, and defined various indices, which were shown to be different by sex or side in a previous study.[19]

In the present study, we have investigated the association of grip strength and independence of ADL in older adults, comparing the data from our newly-developed device and the internationally utilized BI to determine whether the newly advocated indices are associated with limitations in ADL. Maximum grip strength was proved to be a very good index, which could be shown with precise values; however, response time, values at the turning point and ratio of strength (turning point/maximum strength), although correlated with the indices, varied by sex or hand side (Tables 3 and 4). When we first introduced this device, we thought that not only measuring the maximum strength, but also the time to reach maximum strength, would be important. The time to reach maximum strength, however, was not found to be significant in either sex or in total BI score, or in most of the subclass indices. As a matter of fact, although no association was seen in time to reach maximum strength, some relationships were seen in time to reach turning point and time from turning point to reach maximum, especially in men (Tables 3 and 4). Therefore, the meaning of time might not be the same before and after the turning point. Also, strength at turning point was found to be correlated with total BI score and several subclass items, especially in women.

From the aforementioned, turning point was suggested to be worth measuring, although its meaning warrants further investigation; it could have something to do with the proportional change of the fast and slow twitch fiber contraction, or something else, such as the relative involvement of flexors and extensors in gripping performance. In order to determine this with greater certainty, further studies should be carried out, such as simultaneous electromyography measurement. In the analyses of the separate age groups, particularly in the group of men aged below 70 years, the strength at turning point was associated with total BI scores, although maximum grip strength was not. In the group of women aged below 70 years, in the left hand, neither maximum grip strength nor strength at turning point was related with total BI scores, and some other indices,

Table 5 Partial correlations between nine grip strength items measured and total Barthel Index scores in three different age groups, adjusted by Mini-Mental State Examination score

Age		Men Below 70 years (n = 38)	Men 70s (n = 67)	Men 80s (n = 36)	Women Below 70 (n = 45)	Women 70s (n = 71)	Women 80s (n = 85)
Response time	Right hand	–0.12	–0.34**	–0.14	0.20	–0.08	–0.07
	Left hand	–0.12	–0.33**	–0.40*	–0.33*	–0.27*	–0.09
Time to reach turning point	Right hand	0.16	–0.42**	–0.11	0.01	–0.01	0.08
	Left hand	0.15	–0.27*	–03.2	–0.34*	–0.01	0.06
Strength at turning point	Right hand	0.41*	0.25*	0.26	0.07	0.26*	0.30**
	Left hand	0.35*	0.36**	0.31	0.11	0.22	0.35**
Inclination from start to turning point	Right hand	0.16	0.21	0.31	0.18	0.15	0.14
	Left hand	–0.16	0.28*	0.37*	0.22	0.07	0.18
Time to reach maximum strength	Right hand	0.08	0.06	0.07	–0.10	–0.15	–0.16
	Left hand	–0.23	0.04	–0.1	–0.48**	0.11	–0.02
Maximum strength	Right hand	0.24	0.35**	0.28	0.08	0.16	0.29**
	Left hand	0.09	0.43**	0.30	0.12	0.20	0.35**
Time from turning point to reach maximum strength	Right hand	0.03	0.36**	0.19	–0.11	–0.16	–0.25*
	Left hand	–0.32	0.22	0.16	–0.38*	0.13	–0.07
Ratio of strength (turning point / maximum)	Right hand	0.39*	–0.29*	0.17	0.02	0.23	0.21
	Left hand	0.52**	–0.20	0.22	–0.02	–0.02	0.18
Inclination from turning point to maximum strength	Right hand	–0.07	0.12	0.06	0.15	0.02	0.12
	Left hand	0.07	0.07	–0.03	0.25	0.02	0.17

**$P < 0.01$, *$P < 0.05$.

involving time elements rather than strength were significant. These time-related items were influenced by sex or by side (right or left). This could be as a result of the changes of the quality of the muscle,[22] such as the rates of fast and slow twitch fiber, respectively, or the proportion of the fat infiltration.

As the participants of the present study were assumed to have cognitive problems, we adjusted for MMSE score in the analyses (Tables 3–5). Even after that, however, the results were almost the same in men, with a difference becoming apparent in only one item – inclination from start to turning point. In women, differences became apparent in five items (data not shown), suggesting that cognitive function might be influenced more in women. Further detailed analyses will have to be carried out to elucidate the associations between cognitive function, grip strength and the related new indices. With regard to the association between dementia and gripping performance in particular, further careful studies are required with separation of dementia into vascular, Alzheimer type, Lewy body disease or other types.

So far there have been several studies expressing the association between grip strength and ADL.[11–18] All but one related to ADL performance as a whole.[13] Although most of the studies compared the sex difference, none of them focused on the side difference nor differentiated the subjects by age groups. Thus, to our knowledge, the present study carried out the most detailed analyses to date, such as the subclass items of ADL or the influences of sex, side, or age. Furthermore, we investigated the detailed items during muscle contraction, which were shown for the first time while taking the time axis into consideration. Thus, it has become possible to analyze such detailed items by utilizing our elaborate new device equipped with a machine for quality control in the industrial product field. The detailed indices showed the difference, not only when comparing the difference between an independent group and those with clearly lower levels of ADL, but also with those who require only light assistance (group with total BI score of 95 or 90). This was suggested by the finding that right hand inclination from start to turning point was significantly lower in the 95 and 90 point group than in the 100 point group, although a significant difference was not seen in maximum strength (data not shown), which an ordinary device can measure as a solitary index.

Notwithstanding, the number of participants in the present study might not be large enough to confirm the significance of these indices, as the results on the significance of some of the indices changed when the participants were divided into three different age groups, particularly in women. This was seen in the ratio of strength (turning point/maximum).

There were some limitations to the present study. First, the analyses were carried out only in a Japanese population, and in participants with some cognition problems. Also, although we found some relationships between grip strength and BI scores, they remained rather weak. This might derive from the fact that the distribution of the BI was not even, shifting towards the full or nearly full score group. To more properly assess the influence of gripping performance and ADL, therefore, it might be necessary to use other indices, such as instrumental ADL, or gain a greater number of patients. These are issues to be investigated in future.

For hand side we used right versus left, but it would be more appropriate to consider this based on the hand dominance. However, it was not easy (or simple) to separate the participants by hand dominance, because when asked about their dominancy, 134 male patients replied right, three replied left, three replied both, two replied right but switched from left and eight did not answer. In women, 195 replied right, four replied left, six replied both, one replied right but switched from left and 20 did not answer. We therefore carried out the investigation with the classification of right and left. Nevertheless, for ratio of strength (turning point/maximum), significant correlations were seen with many subitems only in the right hand in both sexes, as was the case for time from turning point to reach maximum strength in men (Tables 3 and 4).

The device itself is still also limited to research purposes, and further improvements must be made to adapt it for more practical use, both in software so that the detailed indices are read automatically, and in hardware, including the handle section, for more comfortable gripping by older adults.

Despite those limitations, however, we will carry out further analyses on the various functions of older adults, by increasing the number of study population, and show the effectiveness of these indices, as the measuring method has advantages: it can be carried out safely and in a very short time with subjects in a sitting position, and can measure isometric contractions that are considered to be proper in measuring strength in elderly people. The device is accurate, of which measuring values (maximum strength) accorded quite well with those of Jamar Hydraulic Hand Dynamometer (data not shown).

In summary, we investigated the association of grip strength and the independence of ADL in older adults, using the data from a newly-developed grip strength measuring device. The maximum grip strength was shown to be associated with ADL in many items of the BI, but some of the newly defined indices, such as response time, strength at turning point, elements regarding before and after turning point until the strength reaches maximum, were shown to be associated with some ADL-related items. Some of the associations were different from those with the maximum grip strength, and they varied by sex, hand side or age groups. This new device, considering the time axis and novel items for measuring, could possibly be used effectively for applications in evaluating the functions of older adults, although further investigations will be required in order to determine the meaning or usefulness of the newly advocated indices.

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Disclosure statement

The authors declare no conflict of interest.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

High prevalence of sarcopenia and reduced leg muscle mass in Japanese patients immediately after a hip fracture

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Aim: Sarcopenia-related falls and fractures are becoming an emerging problem as a result of rapid aging worldwide. We aimed to investigate the prevalence of sarcopenia by estimating the muscle mass of the arms and legs of patients with and without hip fracture.

Methods: This cross-sectional study examined 357 patients immediately after a hip fracture (the HF group) and in 2511 patients from an outpatient clinic who did not have a hip fracture (the NF group) at single institution in Japan. We carried out whole-body dual energy X-ray absorptiometry to analyze body composition with skeletal muscle mass index (SMI; lean mass / height^2) and bone mineral density (BMD). We carried out stepwise logistic regression analysis to determine the factors associated with a hip fracture.

Results: Lower appendicular SMI ($P < 0.001$), leg SMI ($P < 0.001$), and higher prevalence of sarcopenia ($P < 0.001$) were observed in the HF group after controlling for age and sex. The arm SMI was similar in both groups ($P > 0.95$). In multivariate analysis, the presence of sarcopenia, older age and lower BMD were associated with the occurrence of a hip fracture (OR 1.476, $P = 0.002$; OR 1.103, $P < 0.001$; OR 0.082, $P < 0.001$; respectively).

Conclusion: This study showed a higher prevalence of sarcopenia and more reduced leg muscle mass in patients after a hip fracture than in the outclinic patients who did not have hip fractures. The results imply sarcopenia can be a risk factor for a hip fracture. **Geriatr Gerontol Int 2013; 13: 413–420.**

Keywords: dual energy X-ray absorptiometry, hip fracture, osteoporosis, sarcopenia, skeletal muscle mass.

Introduction

As populations are aging worldwide, the number of patients with osteoporotic fracture is increasing. Hip fracture, which is the most common osteoporotic fracture, is one of the most serious and unavoidable medical and social concerns.[1] A fracture of the hip results in increased mortality, persistent physical morbidity[2] and limited activities of daily living (ADL).[3] It is also associated with a high risk of institutionalization,[4,5] readmission[6] and reduction of the quality of life for caregivers.[7] The financial burden on society is becoming more and more critical.[8] Prevention of hip fracture is essential for maintaining a good quality of life for the elderly.

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The role of muscles in maintaining functional performance and preventing falls has been an emphasis in recent years. The mass and strength of skeletal muscles decrease with age, and this loss accelerates after 65 years-of-age with a risk of adverse outcomes, such as physical disability, poor quality of life and death.[9] This condition, called sarcopenia, has received particular attention in recent years.[10,11] In addition to a decrease of physical performance, the elderly with sarcopenia have increased risk of age-related diseases, such as decreased swallowing function[12] or urinary disorder, as a result of muscle dysfunction.[13] Consequently, sarcopenia is regarded as an indicator of development of frailty[14] and loss of independence in the elderly. Furthermore, this condition is also associated with increased physical disabilities, resulting in the risk of falls.[15] However, the impact of sarcopenia on osteoporotic fractures has rarely been reported.

The aim of the present study was to estimate the muscle volume of the extremities and investigate the prevalence of sarcopenia in patients immediately after the occurrence of a hip fracture.

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Methods

The present cross-sectional study examined the reduction of muscle mass of patients with or without hip fracture. Between June 2002 and January 2009, all patients with a fresh hip fracture who were at least 55 years-of-age and admitted to a single study institution in Japan were eligible and assigned to the hip fracture group (HF group). Exclusion criteria were the refusal to give informed consent or inability to carry out whole-body dual energy X-ray absorptiometry (DXA) within 48 h of admission. DXA evaluation, not only of the lumbar spine or hip regions, but also of the whole body, was routinely applied for the diagnosis of osteoporosis at the study institution. Patients who visited the outpatient clinic of the study institution and received DXA during the same period were assigned to the non-fracture group (NF group) if they had no previous history of hip fracture. The study protocol was approved by the Institutional Review Board of the National Center for Geriatrics and Gerontology, and all patients gave detailed written informed consent.

During the study period, 422 acute hip fracture patients aged 55 years and older were admitted to the study institution. Of these patients, 34 (8.1%) were excluded because there was no time to carry out DXA preoperatively due to the need for urgent surgical repair, and 31 (7.3%) were excluded because they or their family were unable to give informed consent. The final study population of 357 participants for the HF group (304 females, 82.7 ± 9.3 years and 53 males, 80.3 ± 9.4 years) did not differ significantly from the non-participants with regard to age, sex, height or bodyweight. During the same period, 2816 consecutive patients aged over 55 years without a history of hip fracture visited the outpatient clinic of the same study institution to check their bone mineral density (BMD) by DXA. Of these patients, 305 were excluded from the study because they received only lumbar or hip DXA and lacked the data of whole-body DXA. Finally, 2511 patients (1893 females, 70.5 ± 11.1 years and 618 males, 67.5 ± 11.6 years) received whole-body DXA and were assigned to the NF group.

Body composition was measured by whole-body DXA (DPX-NT; GE Medical Systems Lunar, Madison, WI, USA). Bone mineral content, fat mass and lean soft-tissue mass were measured separately for each part of the body, including the arms and legs. The lean soft-tissue masses of the arms and legs were nearly equal to the skeletal muscle mass. As absolute muscle mass correlates with height, the skeletal muscle mass index was calculated by the following formula: lean mass (kg) / height^2 (m^2), which is directly analogous to body mass index (BMI; weight [kg]/height^2 [m^2]). Arm skeletal muscle mass index (arm SMI) was defined as (arm lean mass [kg]/height^2 [m^2]). Leg skeletal muscle mass index (leg SMI) was defined as (leg lean mass [kg]/height^2 [m^2]). Appendicular skeletal muscle mass index (appendicular SMI) was defined as the sum of the arm SMI and the leg SMI.[16] Appendicular SMI is commonly used to assess muscle mass in various sarcopenic studies.[9] Sarcopenia was defined according to the criteria for the Japanese based on the report by Sanada *et al.* [7] The value of the Japanese criterion was calculated as below two standard deviations (SD) of the mean appendicular SMI of 569 Japanese healthy volunteers whose ages ranged from 18 to 40 years. The criterion value was an appendicular SMI below 5.46 kg/m^2 in women and below 6.87 kg/m^2 in men. We simultaneously measured the BMD of the whole body, including the lumbar spine, by DXA for all of the participants in the present study.

We used Mann–Whitney's *U*-test to estimate the patient characteristics between the study groups. To compare the prevalence of sarcopenia, we carried out χ^2-test and Fisher's exact test. To find a significant relationship between appendicular SMI and BMD, Pearson's correlation was carried out in each group. We evaluated the appendicular SMI value on continuous variables by using a general linear model to control with covariates as age and sex.[18] The general linear model is a generalization of multiple linear regression model to the case of more than one dependent variable.[19,20] Prevalence of sarcopenia was calculated according to four age groups (age less than 70 years, between 70 years to 74 years, between 75 years to 80 years, more than 80 years). The Mantel–Haenszel method was used for testing significance for age–sex adjusted prevalence of sarcopenia.

To determine the presence of the sarcopenia as an independent variable in predicting the occurrence of hip fracture selected as dependent variables, we used the stepwise multiple logistic regression model. The regression model also included the patient characteristics of age, sex, whole body BMD, weight and height, which were known to be the key predictors for skeletal muscle mass.[18] The strength of association of the chosen variables and the occurrence of hip fracture was reported as the odds ratio (OR) and 95% confidential intervals (CI) in relation to a reference group.

Statistical analyses were carried out using SPSS for Windows software (version 19.0; SPSS, Chicago, IL, USA). A *P*-value of <0.05 was considered significant.

Results

Table 1 shows the characteristics, body composition and skeletal muscle mass index of the patients included in the present study. All the patients (both men and women) in the HF group were older adults. The height, weight and BMI were significantly lower in the HF

Table 1 Characteristics of participants, body composition and skeletal muscle mass index in both males and females

Characteristics	Females HF group ($n = 304$)	NF group ($n = 1893$)	P value	Males HF group ($n = 53$)	NF group ($n = 618$)	P-value
Age (years)	82.7 ± 9.3	70.5 ± 11.1	<0.001	80.3 ± 9.4	67.5 ± 12.9	<0.001
Height (cm)	146.2 ± 7.2	149.5 ± 6.9	<0.001	160 ± 8.7	163.1 ± 7	0.004
Weight (kg)	43.1 ± 9	50 ± 9.8	<0.001	51.4 ± 10.6	60.3 ± 12.2	<0.001
BMI (kg/m²)	20.1 ± 3.6	22.3 ± 3.7	<0.001	20 ± 3.3	22.6 ± 3.7	<0.001
Whole body BMD (g/cm²)	0.84 ± 0.09	0.93 ± 0.12	<0.001	0.86 ± 0.13	1.02 ± 0.2	<0.001
Whole-body T-score	−3.29 ± 1.29	−2.08 ± 1.51	<0.001	0.95 ± 0.11	1.09 ± 0.15	<0.001
Whole-body bone mineral content (kg)	1.25 ± 0.33	1.62 ± 0.40	<0.001	1.81 ± 0.36	2.33 ± 0.53	<0.001
Whole-body fat tissue mass (kg)	9.67 ± 6.68	15.11 ± 7.28	<0.001	8.55 ± 6.57	13.63 ± 7.18	<0.001
Whole-body lean mass (kg)	30.72 ± 3.77	32.61 ± 4.01	<0.001	39.35 ± 5.59	43.55 ± 6.52	<0.001
Arm bone mineral content (kg)	0.14 ± 0.05	0.18 ± 0.05	<0.001	0.25 ± 0.07	0.31 ± 0.08	<0.001
Arm fat tissue mass (kg)	0.95 ± 0.84	1.49 ± 0.88	<0.001	0.70 ± 0.66	1.11 ± 0.7	<0.001
Arm lean mass (kg)	2.98 ± 0.95	3.16 ± 0.67	<0.001	4.18 ± 1.16	4.67 ± 1.03	<0.001
Arm SMI (kg/m²)	1.40 ± 0.45	1.41 ± 0.28	0.001	1.64 ± 0.48	1.75 ± 0.35	0.006
Leg bone mineral content (kg)	0.40 ± 0.13	0.55 ± 0.15	<0.001	0.66 ± 0.18	0.84 ± 0.19	<0.001
Leg fat tissue mass (kg)	3.08 ± 2.02	4.51 ± 2.19	<0.001	2.69 ± 1.92	3.56 ± 1.85	<0.001
Leg lean mass (kg)	9.1 ± 1.72	10.11 ± 1.72	<0.001	11.48 ± 2.12	13.39 ± 2.59	<0.001
Leg SMI, kg/m² (kg)	4.27 ± 0.77	4.51 ± 0.65	<0.001	4.49 ± 0.82	5.01 ± 0.76	<0.001
Appendicular SMI† (kg/m²)	5.66 ± 1.04	5.92 ± 0.84	<0.001	6.13 ± 1.2	6.76 ± 1.01	<0.001

All data were expressed as mean ± SD. All *P*-values were from Mann–Whitney's *U*-test. †Appendicular skeletal muscle mass index (SMI) is defined as the sum of leg SMI and arm SMI. BMD, bone mineral density; BMI, body mass index; HF group, hip fracture group; NF group, non-fracture group; SD, standard deviation.

group for females and males. Whole-body lean mass and fat mass were significantly low in both men and women in the HF group.

For adjusting the differences of age and the ratio of females between the NF group and the HF group, general linear model analysis was used to compare the characteristics, body composition and skeletal muscle mass index of patients in both the study groups, after controlling for age and sex (Table 2). No differences were observed in height, after controlling for age and sex. The weight, BMI and whole-body BMD significantly decreased in patients in the HF group. No significant difference in the arm SMI was observed between the HF and NF groups. In contrast, the patients in the HF group had significantly lower leg SMI than those in the other groups. The appendicular SMI – which was the sum of the arm SMI and leg SMI – also decreased in patients in the HF group, even after controlling for age and sex. No difference was observed in the whole-body lean mass. The prevalence of sarcopenia was significantly higher in the HF group after adjusting by age and sex with the Mantel–Haenszel method.

A stepwise logistic regression analysis was carried out to identify predictive factors for the occurrence of a hip fracture. We found that the presence of sarcopenia, older age and lower whole-body BMD were significant factors for the occurrence of a hip fracture ($P = 0.002$, $P < 0001$ and $P < 0.001$, respectively; Table 3).

Table 4 shows the estimated prevalence of sarcopenia in each age group of the HF and NF group patients. The prevalence of sarcopenia was higher in every age group of the HF group, and there were significances in the females in the 70–74 years group and 74–80 years group ($P = 0.004$, $P = 0.001$, respectively).

Overall in the HF group, the prevalence of sarcopenia in women and men was 44.7% and 81.1%, respectively; overall in the NF group, it was 27.2% and 52.8%, respectively. Sarcopenia prevalence was significantly higher in both men and women overall in the HF group than in the NF group. For comparing the prevalence of sarcopenia between males and females, differences were not observed in the group aged less than 70 years ($P > 0.95$) and in the group aged between 70 and 74 years ($P = 0.598$) in the HF group. However, this prevalence was significantly higher in men than in women aged between 75 and 80 years ($P = 0.005$) and those aged more than 80 years ($P < 0.001$). In the NF group, sarcopenia prevalence was high in all patients from all age groups ($P < 0.001$).

The relationship between muscle volume and bone mineral density in each group is shown in Figure 1.

Table 2 Characteristics of participants, body composition, skeletal muscle mass index, and prevalence of sarcopenia in the fracture and non-fracture group controlled by the general linear model procedure

Characteristics	HF group	NF group	*P*-value
Height (cm)	152.5 ± 0.34	152.3 ± 0.14	>0.95
Weight (kg)	48.8 ± 0.54	51.9 ± 0.19	<0.001
BMI (kg/m²)	20.7 ± 0.21	22.3 ± 0.081	<0.001
Whole-body BMD (g/cm²)	0.93 ± 0.0061	0.97 ± 0.0024	<0.001
Whole-body T-score	−2.47 ± 0.77	−1.88 ± 0.30	<0.001
Whole-body bone mineral content (kg)	1.57 ± 0.020	1.77 ± 0.0079	<0.001
Whole-body fat tissue mass (kg)	11.31 ± 0.39	14.54 ± 0.15	<0.001
Whole-body lean mass (kg)	34.55 ± 0.24	35.02 ± 0.96	0.458
Arm bone mineral content (kg)	0.19 ± 0.003	0.19 ± 0.001	<0.001
Arm fat tissue mass (kg)	1.07 ± 0.046	1.39 ± 0.018	<0.001
Arm lean mass (kg)	3.48 ± 0.043	3.50 ± 0.017	>0.95
Arm SMI (kg/m²)	1.48 ± 0.018	1.50 ± 0.070	>0.95
Leg bone mineral content (kg)	0.54 ± 0.007	0.61 ± 0.003	<0.001
Leg Fat tissue mass (kg)	3.50 ± 0.11	4.23 ± 0.045	<0.001
Leg lean mass (kg)	1.05 ± 0.099	1.08 ± 0.039	<0.005
Leg SMI (kg/m²)	4.45 ± 0.038	4.64 ± 0.015	<0.001
Appendicular SMI (kg/m²)	5.93 ± 0.020	6.13 ± 0.050	<0.001
Prevalence of sarcopenia (%)	47.4	31.9	<0.001†

All data were controlled with age and sex. All data except the prevalence of sarcopenia were expressed as mean ± SE. *P*-values were obtained using the general linear model procedure except for prevalence of sarcopenia. †A *P*-value was obtained using the Mantel–Haenszel method after adjusting for age and sex. BMD, bone mineral density; BMI, body mass index; HF group, hip fracture group; NF group, non-fracture group; SE, standard error; SMI, skeletal muscle mass index.

Table 3 Stepwise logistic regression analysis for a hip fracture

	B	OR	95% CI	*P*-value
Presence of sacopenia	0.389	1.476	1.154–1.888	0.002
Age	0.098	1.103	1.087–1.120	<0.001
Whole-body BMD	−3.587	0.082	0.009–0.087	<0.001

The dependent variable was the occurrence of a hip fracture. The presence of sarcopenia was conventionally attributed a value of 1, the absence of sarcopenia was attributed a value of 0. BMD, bone mineral density; CI, confidence interval; OR, odds ratio.

Table 4 Prevalence of sarcopenia in both males and females from each age group

Age (years)	Females			Males		
	HF group	NF group	*P*-value	HF group	NF group	*P*-value
<70	37.5% (12/32)	22.7% (196/864)	0.051*	42.9% (3/7)	37.6% (120/319)	>0.95**
70–74	50.0% (11/22)	22.7% (80/352)	0.004*	75.0% (3/4)	55.7% (64/115)	0.631**
75–80	51.1% (23/45)	26.8% (77/287)	0.001*	92.9% (13/14)	70.7% (65/92)	0.107**
80<	43.9% (90/205)	41.3% (161/390)	0.539*	85.7% (24/53)	83.7% (77/92)	>0.95**
All Age	44.7% (136/304)	27.2% (514/1893)	<0.001*	81.1% (43/53)	52.8% (326/618)	<0.001*

P-values were obtained using the *χ^2-test and **Fisher's exact test. HF group, hip fracture group; NF group, non-fracture group.

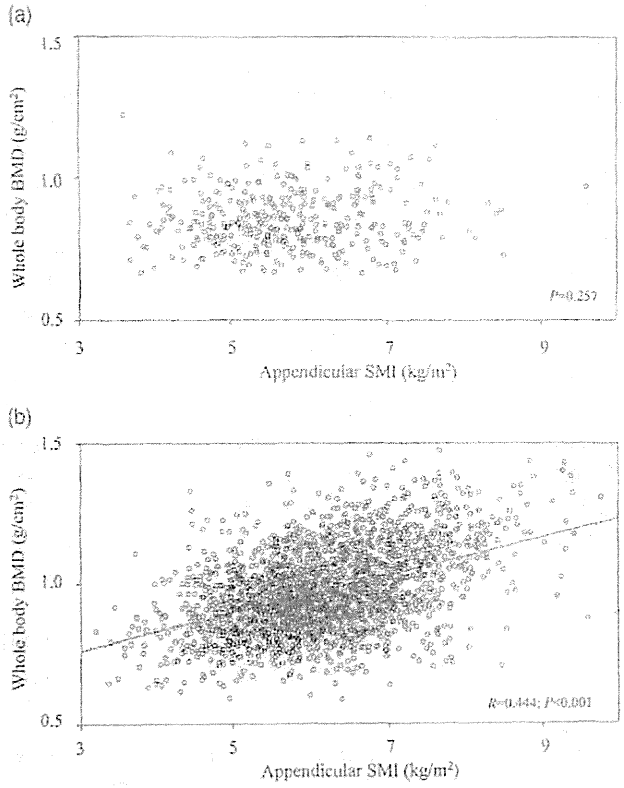

Figure 1 Correlation of appendicular skeletal muscle mass index (SMI) and whole-body bone mineral density (BMD) in (a) the hip fracture (HF) group and (b) the non-fracture (NF) group. *P*-values were from Pearson's test.

There was no significant difference in the HF group ($P = 0.257$). In contrast, there was a positive correlation between appendicular SMI and whole-body BMD in the NF group. ($R = 0.444$; $P < 0.001$).

Discussion

Sarcopenia, which is a barometer of disability and frailty, is one of the most crucial problems for the elderly. In contrast, hip fracture is already known to affect the morbidity and ADL of osteoporotic patients. The relationship between sarcopenia and hip fracture, however, has not been extensively examined. The present study examined the prevalence of sarcopenia in hip-fractured Japanese older adults diagnosed by DXA imaged within 48 h of their hip fracture occurrence, and hospital controls defined as appendicular muscle mass two standard deviations below the healthy normal young population.

The prevalence of sarcopenia in community-dwelling women aged more than 80 years in New Mexico, as reported by Baumgartner *et al.*, was 43.2% for Caucasians and 60% for Hispanics.[18] In the current study, the prevalence of sarcopenia in Japanese women aged more than 80 years without fracture was 41.3%. The prevalence of sarcopenia of women aged 70–80 years of age in New Mexico was 23.1–35.9% and that of Japanese women in the present study was 22.7–26.8%. These are consistent with Baumgartner's findings. An earlier study reported the prevalence of sarcopenia in 313 hip-fractured women whose average age was 79.7 years to be 58%.[21] These patients were diagnosed by DXA at an average of 21 days after occurrence. Estimation of muscle mass in the subacute phase of fracture was affected by surgical intervention and disuse atrophy, and had the possibility of overestimation of the prevalence of sarcopenia. Therefore, the prevalence of sarcopenia in their study might be higher than the real value. In contrast, the present results are regarded as more accurate, because we measured muscle mass in the short-term after the fracture.

In the present study, 44.7% of female and 81.1% of male patients with an acute phase of hip fracture were found to be sarcopenic; sarcopenia prevalence was significantly higher in patients with hip fractures than those without hip fractures, even when adjusted for age and sex. Sarcopenia prevalence was observed to be higher in men with hip fractures than in women with hip fractures. Men with hip fractures were found to have high mortality levels.[22,23] A high prevalence of sarcopenia might reflect the poor general health or frail condition of the patient. For example, the glucose tolerance was impaired, and elevated glycated hemoglobin was observed in sarcopenic patients.[17,24] The risk of nosocomial infection was doubled for patients with sarcopenia in geriatric wards.[25] Montano-Loza *et al.* recently mentioned in their paper that sarcopenia was an independent risk factor for mortality in patients with liver cirrhosis.[26] Szulc *et al.* reported that the loss of appendicular skeletal muscle mass was a predicting factor for mortality in older men.[27] Sarcopenia diagnosed using DXA should be considered as an important indicator of frailty in men.

Muscle volume and strength are the main factors to maintain the motor function of aged people. A number of studies have shown the relationship between sarcopenia and falls. Baumgartner *et al.* reported that people with lower appendicular SMI had a higher incidence of falls and lower body balance.[18] In a cohort study of 2148 English participants, Sayer *et al.* observed that patients with a history of falls presented with significantly lower muscle power.[28] According to a 5-year prospective study with 141 participants, the risk of deteriorated ADL doubled for those participants with decreased appendicular skeletal muscle.[29]

Furthermore, the muscle mass of the lower extremities was significantly decreased in patients with hip fracture in the present study. In contrast, the muscle mass of the arm did not differ regardless of hip fracture. This result supports previous reports about that the attenuation of leg muscle increasing the risk of falls and hence fractures.[30–32] The sarcopenic leg, or the muscle decrease and weakness of lower extremities, was already known to be associated with poor leg performance,[33,34] and to be a risk factor for recurrent falls and fracture.[35] Although handgrip strength instead of knee flexion/extension strength was recommended as a diagnosis tool in a European consensus on the definition and diagnosis of sarcopenia,[9] the measurement of muscle mass and strength of the lower extremities can be valuable for predicting the fracture risk of a hip.

In addition, there was a significant positive correlation between muscle mass and BMD in patients without a hip fracture in the present study, a finding that is compatible with past reports.[32,36,37] The mechanisms underlying disease, such as malnutrition, insufficiency of vitamin D and lack of physical activity, are common to sarcopenia and osteopenia.[38] In contrast, our study showed the BMD and appendicular SMI were not correlated significantly for the patients in the acute phase after occurrence of a hip fracture. Patients with a hip fracture had developed more severe sarcopenia and osteoporosis, as shown in Table 1. There was the speculation that the BMD and appendicular SMI were not correlated in patients who were especially frail. Furthermore, multivariate analysis showed that not only low BMD, but also the presence of sarcopenia, was a potential risk factor for an osteoporotic fracture. Simultaneous muscle and bone loss causes more severe instability in the frail elderly, which leads to falls and subsequent fracture.

Several ways to assess muscle volume have been established. Evaluation of the thigh muscle cross-sectional area by computed tomography or magnetic resonance imaging is the gold standard measurement for research,[9] but various limitations, such as high cost, the invasiveness of radiation and poor accessibility, have been reported. DXA is a precise and reproducible, as well as more accessible, less invasive and lower-costing alternative.[39] The technical errors of DXA compared with computed tomography were reported to be just 2.5%.[40] Anthropometric measurements, including calf circumference, are the traditional and convenient way to estimate skeletal muscle mass, but their accuracy is inadequate for the screening of sarcopenia.[41] Bioelectrical impedance analysis for sarcopenia is also a non-invasive and easy-to-use method. However, its validity has not been ascertained for those patients whose hydration status alters, such as the extremely elderly and fractured patients.[42] Currently, DXA is the preferred measurement method for clinical and research use.

The present study had several limitations. The participants in the NF group were neither randomly selected residents nor healthy volunteers. They were those patients who were suspected to be osteoporotic at our outpatient clinic. Because there is positive relationship between muscle mass and BMD, the patients with osteoporosis were estimated to have a higher prevalence of sarcopenia. We probably underestimated the difference of skeletal muscle mass between the hip fracture patients and the normal population. The second limitation is that we did not assess the function of the muscle, menopause status, comorbidities, the degree of pre-injury daily activity and energy expenditure in the present study. Recent reports mentioned that bed rest and low energy intake of inpatients might affect sarcopenia and hospitalization-associated disability.[43,44] However, the present study estimated the muscle mass within only 48 h from admission and the effect was limited. It is also well known that muscle strength declines much more rapidly than muscle mass, and sometimes the declines of muscle mass and strength were different between elderly individuals.[45] In future studies, we need to take into account a larger number of such covariates, which might confound the muscle mass–fracture relationship. There is another limitation about the sample size to evaluate the prevalence of sarcopenia in the each age group (Table 4). Our sample size analysis carried out with G*Power software (version 3.1.3, Faul *et al.*;[46] Heinrich-Heine-University, Dusseldorf, Germany) showed that statistical power for the female group aged <70 years, 70–74 years, 75–80 years, >80 years and all ages were 17.4%, 90.0%, 95.6%, 15.0% and 100%, respectively. Statistical power for the male age groups were <70 years, 70–74 years, 75–80 years, >80 years and all ages were 8.8%, 18.8%, 55.2%, 8.2% and 99.2%, respectively. Although adequate sample size was not mandatory, because the present study was an exploratory study, calculated statistical power over 80% was generally optimal for a significant result. A further study is required to validate the results in another dataset with a sufficient number of cases in the groups with inadequate statistical power, such as all age groups of the male and female group aged less than 70 years.

In conclusion, the present study showed that a higher prevalence of sarcopenia in Japanese patients in the acute phase of hip fracture than those patients from outclinics who did not have hip fractures, and that leg muscles of patients with a hip fracture were more sarcopenic. The diagnosis of sarcopenia and the evaluation of leg muscle by DXA can be the key to estimating patients at risk of a hip fracture.

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ORIGINAL ARTICLE

Risk factors for a poor outcome following surgical treatment of cervical spondylotic amyotrophy: a multicenter study

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Abstract
Introduction Cervical spondylotic amyotrophy (CSA) is characterized by muscle atrophy in the upper extremities without gait disturbance. However, the indications and outcomes of surgical treatment for CSA have not been clarified. The purpose of this study was to determine the risk factors for a poor outcome following surgical treatment of CSA.
Materials and methods We performed a retrospective review of CSA in patients from 1991 to 2010 through a multicenter study. We collected information regarding age, type of muscle atrophy, preoperative manual muscle test (MMT), duration of symptoms, high-intensity areas on T2-weighted MR images, low-intensity areas on T1-weighted MR images, levels of spinal canal stenosis, cervical kyphosis and surgical procedures (laminoplasty, anterior cervical discectomy and fusion and posterior spinal fusion), and calculated overall risk factors related to a poor outcome following surgery. Univariate analyses and multivariate logistic regression analysis were performed to identify correlates of a poor outcome.
Results Fifty-nine patients, 95 % male (56 patients), were included in our analysis with a mean age of 59 years (range 32–78 years). Eighteen patients did not improve after surgery. Symptom duration (OR = 1.263), preoperative MMT grade (OR = 0.169) and distal type of CSA (OR = 9.223) were all associated with an increased risk of a poor surgical outcome.
Conclusion Early surgery is recommended for CSA patients in whom conservative treatment has not been successful. We also recommend surgery for patients who have severe preoperative muscle weakness or have the distal type of CSA.

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Keywords Cervical spondylotic amyotrophy · Poor outcome · Risk factor · Surgical treatment

Abbreviations

CSA	Cervical spondylotic amyotrophy
CSM	Cervical spondylotic myelopathy
ALS	Amyotrophic lateral sclerosis
MMT	Manual muscle test
HIA	High-intensity areas
LIA	Low-intensity areas
ACDF	Anterior cervical discectomy and fusion
PSF	Posterior spinal fusion
OR	Odds ratio
EMG	Electromyography

Introduction

In 1952, Brain et al. [1] first reported on a case of cervical spondylosis with muscle atrophy of the upper extremities but without sensory disturbance. Keegan [2] later reported on this case at autopsy and described this condition as dissociated motor loss in the upper extremities with cervical spondylosis. In Japan, Yanagi et al. [3] labeled this condition "Cervical Spondylotic Amyotrophy (CSA)". After analyzing the clinical features of CSA, they concluded that this condition was caused, not only by mechanical compression of the spinal cord, but also by selective damage to the anterior horn of the spinal cord secondary to circulatory disturbance. Kameyama et al. [4] reported that the pathophysiological basis for this syndrome was multisegmental damage possibly caused by circulatory insufficiency.

Cervical spondylotic amyotrophy is classified as either a proximal or distal type of muscle atrophy. The proximal type of CSA is characterized as weakness of the deltoid and biceps, such as a drop shoulder, whereas, the distal type is characterized as weakness of the hand muscles such as a drop finger. CSA patients are in their 30s–70s, but most are over 50 years old.

Usually, patients with CSA are first treated conservatively, such as with cervical traction or a neck collar. If the conservative treatment is ineffective, surgery is performed. Most cases have been successfully treated with surgery [5–7]; however, some surgeries have resulted in poor outcomes. It is in the best interest of patients and surgeons to understand potential risk factors related to a poor outcome following surgery. Several studies on CSA mentioned risk factors related to a poor outcome following surgery [6, 7], but there has not been a full multivariate analysis on this type of data. To the best of our knowledge, this is the first report incorporating a multivariate analysis on the results of surgical treatment for CSA. Our goal was to conduct a retrospective case–control study and multivariate analysis to assess the risk factors for a poor outcome after surgical treatment for CSA.

Materials and methods

All institutions that participate in the Nagoya Spine Group (NSG) obtained institutional review board approval for this study. We performed a retrospective review on both prospectively and retrospectively collected data for this study. The medical records of patients who underwent surgical treatment from January 1991 to December 2010 were reviewed to identify those who did not improve after CSA surgery. Orthopedic spine surgeons performed all the surgical procedures on 59 patients with CSA at hospitals in the NSG. Ten institutions participated in this multicenter study, and 18 surgeons performed the operations on CSA patients. We collected data on patients' ages, types of muscle atrophy, preoperative manual muscle test (MMT) results, duration of symptoms, high-intensity areas (HIA) on T2-weighted MR images (both sagittal and axial views), low-intensity areas (LIA) on T1-weighted MR images, levels of spinal canal stenosis, presence of cervical kyphosis and surgical procedures [laminoplasty, anterior cervical discectomy and fusion (ACDF) and posterior spinal fusion (PSF)]. We examined those factors related to poor outcomes following CSA surgery by applying univariate analyses and multiple logistic regression analysis of the surgical outcomes. To evaluate the effect of surgical treatment, we used MMT, and improvements in the muscle strength of the most atrophic and impaired muscles were classified into 4 grades: "excellent", full recovery or recovery to a MMT grade of 2; "good", 1 grade of recovery; "fair", no improvement; "poor", worsening effect. Taken together, we categorized two groups: a good outcome included "excellent" and "good"; a poor outcome included "fair" and "poor". We performed statistical analyses between the two groups.

To differentiate between amyotrophic lateral sclerosis (ALS) and CSA, we always examined for the presence of sensory disturbance, bulbar symptoms and diffuse muscle atrophy, and also performed electromyography (EMG) in some cases before surgery. Furthermore, a neurologist ascertained that these patients did not have motor neuron disease before surgery. Finally, there were no cases which were diagnosed as ALS or other motor neuron disease after surgery.

Data analysis

Data were analyzed using SPSS (version 18.0). Univariate analyses were performed to examine the relationship between outcome at the final follow-up and prognostic factors. We used Mann–Whitney *U* tests for non-normally distributed variables, and Chi-square tests for categorical variables. Variables were included in a logistic regression model if their univariate analysis p value was ≤ 0.15. The threshold for significance was a p value of <0.05.

Results

A total of 59 patients with CSA underwent surgical treatment. There were 56 men and 3 women, with an average age of 59.4 years (range 32–78 years). The mean follow-up period was 2.7 years (range 1–12 years and 9 months). The duration of symptoms averaged 11.4 months (range 0.8 months to 15 years). Forty-one patients had proximal-type CSA, and 18 patients had distal-type CSA. HIA on T2 MRI was confirmed in 21 of 59 patients, and LIA on T1 MRI was confirmed in five of 59 patients. Spinal canal stenoses were found at an average of 2.7 intervertebral levels (range 1–5 levels). Forty-five patients received laminoplasty with or without foraminotomy, eight patients received ACDF, and six patients received PSF with laminoplasty/laminectomy. The surgical results were excellent for 33 patients, good for 8, fair for 17, and poor for 1 (Table 1). On univariate analyses of surgical outcomes, the duration of symptoms and preoperative MMT grade were statistically associated with a poor outcome after surgery ($p < 0.05$). There was a trend for patients with the distal type of muscle atrophy to have a poorer surgical outcome compared to patients with the proximal type of muscle atrophy ($p = 0.123$). Also, there was a trend in patients who received ACDF to have a better surgical outcome compared to patients receiving other surgical procedures ($p = 0.09$) (Table 2). As described in the "Materials and methods" section, potentially significant predictors of a poor outcome were used to fit a logistic regression model. On multivariate analyses of surgical outcomes, preoperative MMT grade and distal-type CSA were significant predictors of poor surgical outcome ($p \leq 0.05$) (preoperative MMT grade: OR = 0.169, and distal type of CSA: OR = 9.223), whereas, symptom duration was a highly significant predictor (OR = 1.263, $p \leq 0.001$). However, type of surgical procedure was not significantly associated with a poor surgical outcome. The full model is presented in Table 3.

Table 1 Demographic data of CSA patients

	All patients (n = 59)
Mean age (years)	59.4 (32–78)
Male/female	56/3
Mean follow-up (years)	2.7
Duration of symptoms (months)	11.4
Type of muscle atrophy	
Proximal	41
Distal	18
Preoperative MMT grade	2.3
Levels of stenosis	2.7
HIA on T2 MRI	21
LIA on T1 MRI	5
Kyphosis	17
Surgical procedure	
Laminoplasty	45
ACDF	8
PSF + laminoplasty/laminectomy	6
Surgical outcome	
Excellent	33
Good	8
Fair	17
Poor	1

CSA cervical spondylotic amyotrophy, *MMT* manual muscle test, *PSF* posterior spinal fusion, *ACDF* anterior cervical discectomy and fusion, *HIA* high-intensity area, *LIA* low-intensity area

Discussion

In our study, we demonstrated clinical features of CSA and used a logistic regression model to determine the risk factors related to having a poor postoperative outcome. We demonstrated that patients with poor surgical outcomes tended to have CSA symptoms for a longer duration and to have lower preoperative MMT grades than those patients with good outcomes (OR: 1.263, $p = 0.006$; OR: 0.169, $p = 0.015$, respectively). Based on our results, we recommend surgery for CSA patients with MMT grades of 1 or 2, and if conservative treatment has not been successful for 3–6 months. Furthermore, in our study, the surgical outcome for distal-type CSA was inferior to the outcome for proximal-type CSA (OR, 9.223; $p = 0.025$). Similarly, Uchida et al. [7] reported that surgical outcome in patients with the distal type of muscle atrophy was inferior to that in patients with the proximal type. Neuroradiologically, Kaneko et al. [8] mentioned that the pathophysiology of distal-type CSA included widespread gray matter lesions with less involvement of the lateral posterior spinal column. Fujiwara et al. reported that muscle power improved in 92 % of the proximal-type cases but only