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 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).

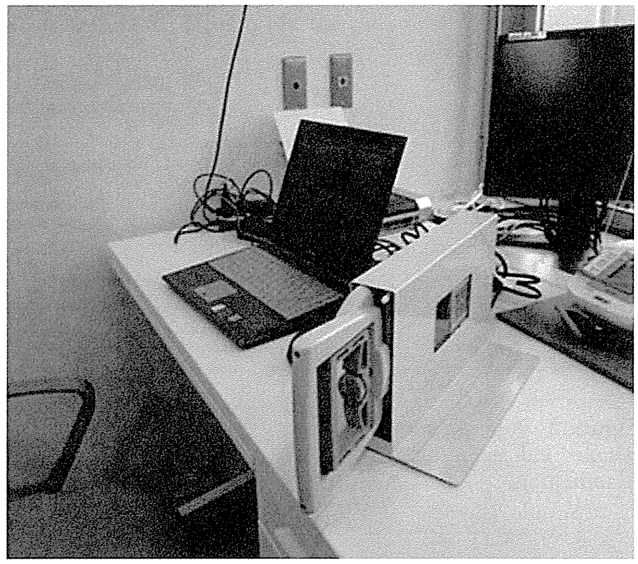

Figure 1 Newly-developed device for measuring grip strength. Force-gauge (made by IMADA, Toyohashi, Japan) can be used for measuring industrial products, such as the operation switch on a deluxe automobile. The gauge is equipped with an easy-grip handle. The signal output from the device is sent to the 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.

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).

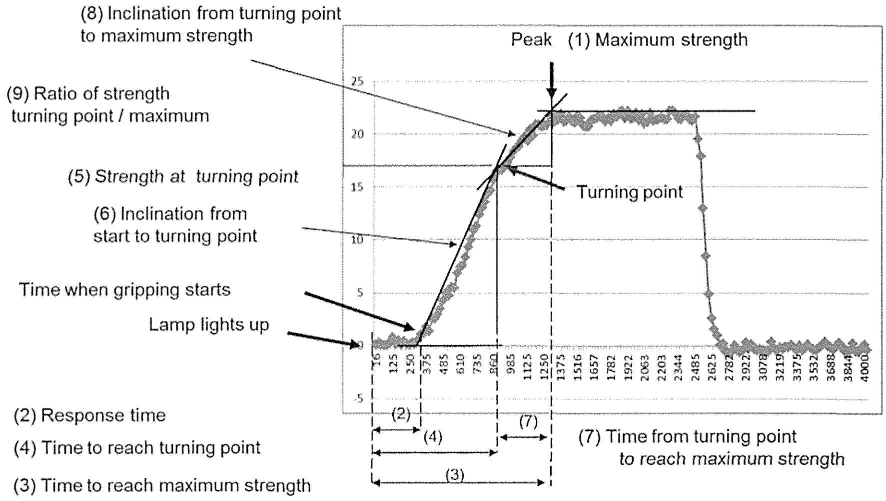

Figure 2 A graph showing nine detailed indices in the agility examination.

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)	70s (n = 67)	80s (n = 36)	Women Below 70 (n = 45)	70s (n = 71)	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.

References

1 Stuck AE, Iliffe S. Comprehensive geriatric assessment for older adults. *BMJ* 2011; **343**: d6799.
2 Arai H, Ouchi Y, Yokode M *et al.* Members of subcommittee for aging. *Geriatr Gerontol Int* 2012; **12**: 16–22.
3 Cruz-Jentoft AJ, Baeyens JP, Bauer JM *et al.* Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. *Age Ageing* 2010; **39**: 412–423.
4 Forrest KY, Bunker CH, Sheu Y, Wheeler VW, Patrick AL, Zmuda JM. Patterns and correlates of grip strength change with age in Afro-Caribbean men. *Age Ageing* 2012; **41**: 326–332.
5 Schlussel MM, dos Anjos LA, de Vasconcellos MT, Kac G. Reference values of handgrip dynamometry of healthy adults: a population-based study. *Clin Nutr* 2008; **27**: 601–607.
6 Lauretani F, Russo CR, Bandinelli S *et al.* Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol* 2003; **95**: 1851–1860.
7 Leal VO, Mafra D, Fouque D, Anjos LA. Use of handgrip strength in the assessment of the muscle function of chronic kidney disease patients on dialysis: a systematic review. *Nephrol Dial Transplant* 2011; **26**: 1354–1360.
8 Moriya S, Tei K, Murata A, Muramatsu M, Inoue N, Miura H. Relationships between Geriatric Oral Health Assessment Index scores and general physical status in community-dwelling older adults. *Gerodontology* 2012; **29**: e998–1004.
9 Patel HP, Syddall HE, Jameson K *et al.* Prevalence of sarcopenia in community-dwelling older people in the UK using the European Working Group on Sarcopenia in Older People (EWGSOP) definition: findings from the Hertfordshire Cohort Study (HCS). *Age Ageing* 2013; **42**: 378–384.
10 Laukkanen P, Era P, Heikkinen RL, Suutama T, Kauppinen M, Heikkinen E. Factors related to carrying out everyday activities among elderly people aged 80. *Aging (Milano)* 1994; **6**: 433–443.
11 Rantanen T, Era P, Heikkinen E. Maximal isometric strength and mobility among 75-year-old men and women. *Age Ageing* 1994; **23**: 132–137.
12 Rantanen T, Era P, Heikkinen E. Physical activity and the changes in maximal isometric strength in men and women from the age of 75 to 80 years. *J Am Geriatr Soc* 1997; **45**: 1439–1445.
13 Simard J, Chalifoux M, Fortin V, Archambault MJ, St-Cerny-Gosselin A, Desrosiers J. Could questions on activities of daily living estimate grip strength of older adults living independently in the community? *J Aging Res* 2012; **2012**: 427109. doi: 10.1155/2012/427109
14 Young DR, Masaki KH, Curb JD. Associations of physical activity with performance-based and self-reported physical functioning in older men: the Honolulu Heart Program. *J Am Geriatr Soc* 1995; **43**: 845–854.
15 Al Snih S, Markides KS, Ottenbacher KJ, Raji MA. Hand grip strength and incident ADL disability in elderly Mexican Americans over a seven-year period. *Aging Clin Exp Res* 2004; **16**: 481–486.
16 Nishiwaki T, Nakamura K, Ueno K, Fujino K, Yamamoto M. Health characteristics of elderly Japanese requiring care at home. *Tohoku J Exp Med* 2005; **205**: 231–239.
17 Rantanen T. Muscle strength, disability and mortality. *Scand J Med Sci Sports* 2003; **13**: 3–8.
18 Sarkisian CA, Liu H, Ensrud KE, Stone KL, Mangione CM. Correlates of attributing new disability to old age. Study of Osteoporotic Fractures Research Group. *J Am Geriatr Soc* 2001; **49**: 134–141.
19 Matsui Y, Fujita R, Harada A *et al.* A new grip-strength measuring device for detailed evaluation of muscle contraction among the elderly 2014 (in press).
20 Wade DT, Collin C. The Barthel ADL Index: a standard measure of physical disability? *Int Disabil Stud* 1988; **10**: 64–67.
21 Harada A, Mizuno M, Takemura M, Tokuda H, Okuizumi H, Niino N. Hip fracture prevention trial using hip protectors in Japanese nursing homes. *Osteoporos Int* 2001; **12**: 215–221.
22 Doherty TJ. The influence of aging and sex on skeletal muscle mass and strength. *Curr Opin Clin Nutr Metab Care* 2001; **4**: 503–508.

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Review Article

Managing Sarcopenia and Its Related-Fractures to Improve Quality of Life in Geriatric Populations

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ABSTRACT: Sarcopenia, an aging-induced generalized decrease in muscle mass, strength, and function, is known to affect elderly individuals by decreasing mobile function and increasing frailty and imbalance that lead to falls and fragile fractures. Sarcopenia is a known risk factor for osteoporotic fractures, infections, and early death in some specific situations. The number of patients with sarcopenia is estimated to increase to 500 million people in the year 2050. Sarcopenia is believed to be caused by multiple factors such as disuse, malnutrition, age-related cellular changes, apoptosis, and genetic predisposition; however, this remains to be determined. Various methods have been developed, but no safe or effective treatment has been found to date. This paper is a review on the association between sarcopenia and its related-fractures and their diagnoses and management methods to prevent fractures.

Key words: sarcopenia, sarcopenia-related fracture, osteoporosis, diagnosis, muscle mass, treatment, pathogenesis

Sarcopenia, an aging-induced decrease in muscle mass, is known to affect elderly individuals by decreasing activities of daily living and increasing frailty and vulnerability to falls and osteoporotic fractures.

In the field of orthopedics, the elements of the musculoskeletal system have been classified as follows: the "muscles," the source of the power; the "tendons," which bind the muscles and the bones; the "bones," which are load-bearing structures; and the "joints," which connect bones with other bones. Thus far, efforts have been made to deepen the understanding of the functions and impairments of each of those elements. Compared with other musculoskeletal disorders such as fractures, osteoarthritis, and tendon or ligament ruptures, muscles have a high capacity to regenerate and are often believed to "heal even without treatment." [1] Unfortunately, there has been a delay in the understanding of the pathophysiology of muscular regeneration and sarcopenia as well as the awareness of treatments. In fact, the regenerative capacity of skeletal muscles is decreased in the elderly; in recent years, it has been found that even when the muscles regenerate, the muscle fibers are abnormal, fatty, and fibrosed [2-4] in aged environment. Such a decrease in muscle mass and strength causes a physical instability that makes the body fall easily, resulting in reduced mobility [5]; and ultimately, the patient experiences falls and fractures and is confined to bed [6, 7].

Sarcopenia has been reported to affect more than 40% of elderly individuals ≥70 years of age, approximately 50 million people worldwide. This number is estimated to increase to 500 million people in the year 2050 [8]. Therefore, there has been major interest in developing strategies to reduce the disadvantage of sarcopenia and help in attenuating the age related decline and disability. In this communication, we comment on the association between sarcopenia and osteoporotic fractures, and the management of sarcopenia to prevent osteoporotic fractures.

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