

Age-related changes in muscle strength and spinal kyphosis angles in an elderly Japanese population

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Abstract: Lumbar kyphosis and the decreased mobility of the lumbar spine increase the risk of falls and impair both the quality of life and the ability to perform activities of daily living. However, in the elderly Japanese population, little is known about the age-related changes and sex-related differences in muscle strength, including of the upper and lower extremities and back extensors. An adequate kyphotic or lordotic angle has also not been determined. In this study, we evaluated the age-related changes in muscle strength and spinal kyphosis in 252 males and 320 females ≥ 50 years of age. Grip, back extensor, hip flexor, and knee extensor strength; thoracic and lumbar kyphosis; and spinal inclination in the neutral standing position were assessed, together with the range of motion of the thoracic and lumbar spine and spinal inclination. Grip strength, back extensor strength, and the strength of the hip flexors and knee extensors decreased significantly with aging, both in males ($P < 0.0001$) and in females ($P = 0.0015$ to $P < 0.0001$). The lumbar but not the thoracic kyphosis angle decreased significantly with aging, only in females ($P < 0.0001$). Spinal inclination increased significantly with aging in both males ($P = 0.002$) and females ($P < 0.0001$). Back extensor strength and the thoracic kyphosis angle were significant variables influencing the lumbar kyphosis angle in both sexes. Spinal inclination correlated significantly with both the lumbar kyphosis angle and hip flexor strength in males, as well as with the lumbar kyphosis angle in females.

Keywords: aging, gender, grip strength, back extensor strength, spinal curvature

Introduction

Aging is associated with progressive physiologic changes that lead to deterioration of the structure and function of the musculoskeletal system.^{1,2} This results in a decline in the functional performance of older adults and often in the eventual need for nursing care or support.^{3,4} Thus, in the elderly, the maintenance of good physical and functional performance is critical to preserve independence and decrease the risk of disability.

Declining muscle strength in the elderly is associated with poor physical performance, an increased risk of falls and disability, poor quality of life (QoL), and increased mortality.⁵⁻⁹ The age-related decline in muscle strength^{1,3} involves both the upper and lower extremities, as well as the lumbar extensors. In the latter muscles, a 50% reduction between the third and sixth decades of life has been reported.^{10,11} However, in the elderly Japanese population, age-related changes and sex-related differences in muscle strength, including that of the upper and lower extremities and back extensors, have not been well studied.

Lumbar kyphosis and the mobility of the lumbar spine are additional important parameters that contribute to determining the QoL of the elderly. An increase in the thoracic kyphosis angle during aging has also been reported,^{12,13} especially in females.¹⁴ Previous studies of elderly Japanese have shown that lumbar kyphosis,

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decreased mobility of the lumbar spine, and an increase in spinal inclination, but not thoracic kyphosis or thoracic spine mobility, are also related to an increased risk of falls.^{9,15} In a previous work, we demonstrated that back extensor strength is a significant determinant of lumbar kyphosis and the mobility of the lumbar spine.^{8,16} The purpose of this study was to evaluate the age-related changes and sex-related differences in muscle strength in the upper and lower extremities as well as the trunk, their associations with spinal alignment and mobility, and the factors significantly associated with lumbar kyphosis and spinal inclination in elderly Japanese. We therefore measured grip, back extensor, hip flexor, and knee extensor strength; the kyphotic angles of the thoracic and lumbar spine; and spinal inclination in community-dwelling Japanese males and females 50 years of age and older.

Methods

Patients and study design

The 252 males and 320 females who participated in this study were ≥ 50 years of age. All 572 participants underwent a medical checkup at municipal health centers between 2009 and 2014. After receiving an explanation of the measurements of muscle strength and spinal kyphosis angle, all subjects provided written informed consent to participate. The study protocol was approved by the ethics committee of Akita University Graduate School of Medicine.

Measurement of muscle strength

Grip strength was measured on the dominant and non-dominant sides using a dynamometer (TTM Dynamometer; Tsutsumi, Tokyo, Japan), with the patient in the upright position. The test was performed twice, and the average of the right and left sides then determined. Muscle strength of the lower extremities, including hip flexors and knee extensors, was measured using a handheld dynamometer (Commander™ PowerTrack II™ Handheld Dynamometer; Nihon Medix Co, Ltd, Matsudo, Japan). The strength of the muscle groups of the lower extremities was measured twice and the average of the bilateral measurements was then determined. Isometric back extensor strength in the prone position was measured using a strain gauge dynamometer (DPU-1000N Digital Force Gauge; Imada, Toyohashi, Japan). The patient's position was aligned with the table and a strain gauge dynamometer was placed in the mid portion (at the inferior aspect of the scapula) of his or her back. The patient was then asked to lift his/her upper trunk as much as possible. Maximum strength was then recorded using the strain gauge. Measurements were performed three times and

the maximum value then selected, as previously described.¹⁶ The coefficient of variation, as an indicator of the precision of the measurement, was 2.3%.⁸

Thoracic and lumbar kyphosis angles and mobility

The kyphosis angle of both the thoracic (T1–T12) and the lumbar (L1–S1) spine (Figure 1) was measured using a computerized measurement device for surface curvature (SpinalMouse®; Idiag, Volkerswill, Switzerland) (Figure 1A), with the patient in the upright position. Spinal inclination, defined as the angle between the line from the center of T1 to S1 and a vertical line originating at S1, was also measured (Figure 1B). By sliding the measurement device along the spinal curve, the spinal kyphosis angles could be calculated. The results were displayed on a computer monitor. Repeating this process with the patient in spinal flexion and extension was interpreted as a measurement of spinal mobility (Figure 1A). The mobility of the spinal inclination reflects the mobility of the trunk, including thoracic, lumbar, and sacral/hip mobility, and was also measured at maximum flexion and extension (Figure 1B). The intraclass coefficients for the curvature measurement with the SpinalMouse were 0.92–0.95.¹⁷

Statistical analyses

The results are expressed as the mean (standard deviation). A Kolmogorov–Smirnov test was performed to confirm the normal distributions of the data for males and females. Inter-group, age-dependent differences in males and females were assessed using a one-way analysis of variance (ANOVA), followed by Scheffe's multiple comparison method as a post hoc test. Correlations between the parameters were analyzed using Pearson's method. Parameters significantly associated with lumbar kyphosis and spinal inclination were identified in a multiple regression analysis. Differences with a P -value < 0.05 were considered statistically significant. All statistical analyses were performed using Statistical Package for the Biosciences software (SPBS version 9.54, developed by Murata K et al., Akita University Graduate School of Medicine, Akita, Japan).¹⁸

Results

Participant characteristics

Table 1 presents the physical characteristics of the participants. The heights and body weights of males and females decreased significantly with aging [$F(3,248) = 15.966$, $P < 0.0001$ and $F(3,248) = 17.138$, $P < 0.0001$ in males, and $F(3,316) = 26.763$, $P < 0.0001$ and $F(3,316) = 4.784$, $P = 0.0028$ in females, respectively], as determined by ANOVA. Body

Segment	Upr	Flex	Ext	U-F	U-E	E-F
Th1/2	-9	0	36	9	45	-36
Th2/3	-16	1	6	17	22	-5
Th3/4	6	7	3	0	-3	4
Th4/5	7	2	-3	-5	-10	5
Th5/6	8	2	3	-6	-5	-1
Th6/7	3	2	0	-1	-3	2
Th7/8	4	5	3	1	-1	3
Th8/9	3	3	-1	0	-5	4
Th9/10	2	6	1	4	-1	6
Th10/11	5	6	-1	1	-6	7
Th11/12	-3	5	6	8	9	-1
Th12/L1	3	6	-6	4	-9	12
L1/2	-7	7	-6	14	1	13
L2/3	6	-2	-7	-8	-12	4
L3/4	-3	3	1	6	4	2
L4/5	-2	3	10	5	11	-6
L5/S1	-25	-3	9	23	34	-11
Sac/Hip	18	84	-39	66	-56	123
ThSp	11	40	53	29	42	-13
LSp	-29	15	1	43	29	14
Incl	-3	107	-24	110	-21	131
Length	462	486	443	24	-20	43

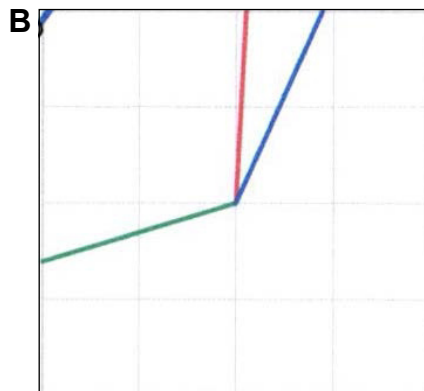
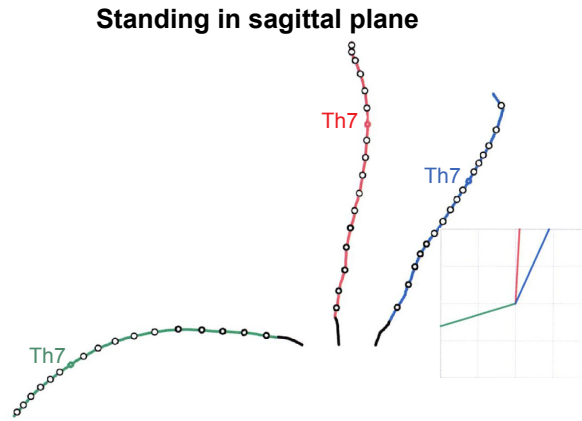


Figure 1 Thoracic kyphosis, lumbar kyphosis, and spinal inclination angles, measured using the SpinalMouse.

Notes: (A) All three angles were measured using the SpinalMouse software, with the patient in neutral (red line), flexed (green line), and extended (blue line) positions. The mobility of these angles from flexion to extension was calculated using the same software. (B) Spinal inclination was defined as the angle between the line from the center of T1 to S1 and a vertical line originating at S1, measured with the patient in neutral (red line), flexed (green line), and extended (blue line) positions.

Abbreviations: Th, thoracic; L, lumbar; Incl, inclination; Upr, upright position; Flex, flexed position; Ext, extended position; U-F, mobility from upright to extended position; U-E, mobility from upright to flexed position; E-F, mobility from extended to flexed position; ThSp, thoracic spine; LSp, lumbar spine.

Table 1 Age-specific characteristics of the study participants

Characteristics	50s	60s	70s	80s	F _{3,248} value of ANOVA	P-value of ANOVA
Male, N	22	79	106	45	–	–
Height, cm	166.1 (7.1)	163.2 (6.2)	158.6 (6.4) ^{a,b}	157.8 (6.2) ^{a,b'}	15.966	<0.0001
Body weight, kg	69.6 (11.5)	64.6 (8.5)	60.2 (8.2) ^{a,b''}	56.0 (7.7) ^{a,b}	17.138	<0.0001
BMI	25.2 (3.4)	24.2 (2.8)	23.9 (2.6)	22.4 (2.3)	6.730	<0.0001
Characteristics	50s	60s	70s	80s	F _{3,316} value of ANOVA	P-value of ANOVA
Female, N	35	126	125	34	–	–
Height, cm	156.1 (6.2)	150.5 (5.3) ^a	148.7 (5.1) ^a	144.7 (5.9) ^{a,b,c}	26.763	<0.0001
Body weight, kg	55.9 (6.4)	53.9 (8.4)	51.3 (8.4) ^{a'}	50.3 (6.8)	4.784	0.0028
BMI	22.9 (2.4)	23.8 (3.7)	23.2 (3.6)	23.9 (3.2)	1.073	0.3608

Notes: Results of an ANOVA with Scheffe's multiple comparison method. Data are presented as the mean (standard deviation). ^aP<0.0001, ^{a'}P<0.01 vs those in their 50s, ^bP<0.0001, ^{b'}P<0.001, ^{b''}P<0.01 vs those in their 60s, ^cP<0.01 vs those in their 70s.

Abbreviations: ANOVA, analysis of variance; BMI, body mass index.

mass index (BMI) significantly decreased with age only in males [$F(3,248) = 6.730, P < 0.0001$].

Grip, back extensor, hip flexor, and knee extensor strength

Table 2 presents the results of strength testing of grip, back extensors, hip flexors, and knee extensors. For this analysis, the participants were divided into age groups by decade. Significant decreases in all four parameters occurred with increasing age in both males [$F(3,248) = 8.415-26.505, P < 0.0001$] and females [$F(3,316) = 5.269-26.720, P = 0.0015$ to $P < 0.0001$].

In males, grip, back extensor, hip flexor, and knee extensor strength were significantly lower in participants in their 70s and 80s than in those in their 50s ($P < 0.05$ to $P < 0.0001$, except knee extensor strength in participants in their 70s) or 60s ($P < 0.05$ and $P < 0.0001$). Grip and back extensor strength was significantly lower in participants in their 80s than in those in their 70s ($P < 0.01$ and $P < 0.05$, respectively).

In females, grip, back extensor, and hip flexor strength were significantly lower in participants in their 70s and 80s than in those in their 50s ($P < 0.05$ to $P < 0.0001$) or 60s ($P < 0.05$ to $P < 0.0001$). Grip strength was significantly lower in participants in their 60s or 80s than in those in their 50s ($P < 0.05$) or 70s ($P < 0.05$). However, knee extensor strength in females was significantly lower only in participants in their 80s vs those in their 70s ($P < 0.01$).

Spinal kyphosis angles and spinal mobility

Table 3 presents the results of the spinal (lumbar and thoracic) kyphosis angle and spinal mobility measurements in males and females.

Males

The thoracic kyphosis angle [$F(3,248) = 2.807, P = 0.0403$] and spinal inclination [$F(3,248) = 5.055, P = 0.0020$], but not the lumbar kyphosis angle, increased significantly with aging. Significant decreases with aging also occurred with respect to the mobility of the thoracic [$F(3,248) = 2.731, P = 0.0444$] and lumbar [$F(3,248) = 6.024, P = 0.0006$] spine, as well as the spinal inclination [$F(3,248) = 6.084, P = 0.0005$], as determined in an ANOVA. Spinal inclination was significantly greater in male participants in their 80s than in those in their 60s ($P < 0.01$) and 70s ($P < 0.05$). The mobility of the lumbar spine and the spinal inclination were significantly lower in participants in their 80s than in those in either their 60s ($P < 0.01$ and $P < 0.05$, respectively) or their 70s ($P < 0.01$ and $P < 0.01$, respectively).

Females

The lumbar kyphosis angle [$F(3,316) = 8.498, P < 0.0001$] and spinal inclination [$F(3,316) = 12.919, P < 0.0001$], but not the thoracic kyphosis angle, increased significantly with aging, as determined by ANOVA. Significant decreases with aging were seen in the mobility of the lumbar spine [$F(3,316) = 7.422, P < 0.0001$] and the spinal inclination [$F(3,316) = 3.051, P = 0.0288$], as determined in an ANOVA. Both the lumbar kyphosis angle and the spinal inclination were significantly reduced in participants in their 60s vs those in their 70s ($P < 0.01$ and $P < 0.05$, respectively) or 80s ($P < 0.01$ and $P < 0.0001$, respectively). The lumbar kyphosis angle was significantly larger in participants in their 80s than in those in their 50s ($P < 0.05$). Spinal inclination was significantly larger in participants in their 80s than in those in their 50s ($P < 0.0001$), 60s ($P < 0.0001$), or 70s ($P < 0.01$). Lumbar spine mobility was significantly greater in female

Table 2 Age-specific muscle strength of the study participants

Strength, kg	50s	60s	70s	80s	$F_{3,248}$ value of ANOVA	P-value of ANOVA
Male, N	22	79	106	45		
Grip	41.8 (8.0)	39.4 (7.3)	34.6 (6.5) ^{a,b}	30.0 (5.4) ^{a,b,c}	25.381	<0.0001
Back extensor	31.4 (13.3)	29.2 (11.4)	20.6 (9.7) ^{a,b}	14.6 (7.0) ^{a,b,c'}	26.505	<0.0001
Hip flexor	21.3 (7.2)	20.4 (6.5)	16.5 (5.7) ^{a",b'}	14.7 (4.9) ^{a',b}	13.241	<0.0001
Knee extensor	18.7 (5.0)	18.5 (6.0)	15.7 (5.7) ^{b"}	13.9 (4.6) ^{a"',b'}	8.415	<0.0001
Strength, kg	50s	60s	70s	80s	$F_{3,316}$ value of ANOVA	P-value of ANOVA
Female, N	35	126	125	34		
Grip	28.0 (5.2)	24.8 (4.5) ^{a"}	22.2 (4.1) ^{a,b'}	19.4 (6.2) ^{a,b,c'}	26.720	<0.0001
Back extensor	20.1 (7.3)	19.1 (6.5)	13.9 (6.2) ^{a,b}	10.6 (7.0) ^{a,b}	25.813	<0.0001
Hip flexor	14.8 (4.4)	14.1 (4.3)	12.5 (4.1) ^{a"',b"}	11.6 (3.2) ^{a"',b"}	6.721	0.0002
Knee extensor	14.6 (4.6)	15.1 (4.8)	13.6 (5.3)	11.6 (3.8) ^c	5.269	0.0015

Notes: Results of an ANOVA with Scheffe's multiple comparison method. Data are presented as the mean (standard deviation). ^a $P < 0.0001$, ^{a'} $P < 0.001$, ^{a''} $P < 0.01$, ^{a'''} $P < 0.05$ vs those in their 50s, ^b $P < 0.0001$, ^{b'} $P < 0.001$, ^{b''} $P < 0.05$ vs those in their 60s, ^c $P < 0.01$, ^{c'} $P < 0.05$ vs those in their 70s.

Abbreviation: ANOVA, analysis of variance.

Table 3 Age-specific spinal kyphosis angles and spinal mobility of the study participants

Characteristics	50s	60s	70s	80s	F _{3,248} value of ANOVA	P-value of ANOVA
Male, N	22	79	106	45		
Angle, degree						
Thoracic kyphosis	32.3 (16.5)	33.9 (14.4)	32.4 (13.4)	39.8 (18.1)	2.807	0.0403
Lumbar kyphosis	-14.6 (8.1)	-13.5 (10.9)	-12.9 (11.4)	-11.5 (13.8)	0.464	0.7078
Spinal inclination	4.9 (4.2)	3.2 (4.5)	3.8 (4.5)	6.4 (5.6) ^{b,c'}	5.055	0.0020
Mobility, degree						
Thoracic spine	27.8 (25.4)	27.9 (24.9)	19.3 (25.1)	17.3 (26.4)	2.731	0.0444
Lumbar spine	42.6 (14.1)	43.2 (18.4)	41.3 (14.6)	30.5 (20.4) ^{b,c}	6.024	0.0006
Spinal inclination	103.1 (33.5)	115.5 (33.8)	117.8 (27.4)	95.8 (35.5) ^{b,c}	6.084	0.0005
Characteristics	50s	60s	70s	80s	F _{3,316} value of ANOVA	P-value of ANOVA
Female, N	(35)	(126)	(125)	(34)		
Angle, degree						
Thoracic kyphosis	32.8 (11.6)	32.6 (14.3)	31.3 (15.6)	34.0 (21.3)	0.347	0.7914
Lumbar kyphosis	-18.2 (8.3)	-18.3 (9.3)	-13.5 (10.6) ^{b'}	-10.1 (14.3) ^{a,b'}	8.498	<0.0001
Spinal inclination	2.2 (4.9)	2.0 (4.2)	3.7 (4.2) ^{b''}	7.5 (7.6) ^{a,b,c}	12.919	<0.0001
Mobility, degree						
Thoracic spine	23.9 (31.3)	23.2 (34.6)	19.8 (25.9)	21.4 (19.1)	0.339	0.7970
Lumbar spine	50.8 (14.8)	48.5 (15.2)	41.0 (17.0) ^{a,b'}	39.4 (16.7) ^{a,b''}	7.422	<0.0001
Spinal inclination	123.5 (29.8)	130.1 (29.4)	119.1 (34.1)	117.5 (30.9)	3.051	0.0288

Notes: Results of an ANOVA with Scheffe's multiple comparison method. Data are presented as mean (standard deviation). ^aP<0.0001, ^{a'}P<0.05 vs those in their 50s, ^bP<0.0001, ^{b'}P<0.01, ^{b''}P<0.05 vs those in their 60s, ^cP<0.01, ^{c'}P<0.05 vs those in their 70s.

Abbreviation: ANOVA, analysis of variance.

participants in their 50s than in those in either their 70s ($P<0.05$) or their 80s ($P<0.05$) and in those in their 60s vs those in their 70s ($P<0.01$) or 80s ($P<0.05$).

Correlations of parameters in males and females

Table 4 presents the results of the Pearson's correlation analysis of the parameters in the 252 males (upper diagonal line) and 320 females (lower diagonal line) included in this study. The results of the lumbar kyphosis angle and spinal inclination measurements are described in the following.

Males

The correlation between lumbar kyphosis angle and height ($r=-0.131$, $P<0.05$), body weight ($r=-0.126$, $P<0.05$), back extensor strength ($r=-0.223$, $P<0.05$), and thoracic kyphosis angle ($r=-0.273$, $P<0.0001$) was significantly negative, as was the correlation between spinal inclination and grip strength ($r=-0.152$, $P<0.05$), back extensor strength ($r=-0.240$, $P<0.05$), and hip flexor strength ($r=-0.184$, $P<0.05$). However, spinal inclination correlated positively with age ($r=0.160$, $P<0.05$) and lumbar kyphosis angle ($r=0.388$, $P<0.0001$).

Table 4 Pearson's correlation of parameters in 252 male (above the diagonal line) and 320 female (below the diagonal line) participants

Characteristics	Age	Height	Weight	GS	BES	HFS	KES	TK	LK	SI	MTK	MLK	MSI
Age		-0.400**	-0.442**	-0.512**	-0.502**	-0.389**	-0.304**	0.091	0.107	0.160*	-0.151*	-0.176*	-0.076
Height	-0.491**		0.640**	0.505**	0.395**	0.273**	0.276**	-0.054	-0.131*	0.004	0.070	-0.026	-0.118
Weight	-0.242**	0.340**		0.564**	0.522**	0.359**	0.300**	-0.091	-0.126*	0.031	0.096	0.055	-0.076
GS	-0.465**	0.462**	0.363**		0.559**	0.341**	0.360**	-0.064	-0.117	-0.152*	0.093	0.065	0.025
BES	-0.444**	0.268**	0.262**	0.433**		0.367**	0.346**	-0.055	-0.223*	-0.240*	0.143*	0.258**	0.171*
HFS	-0.242**	0.199*	0.255**	0.368**	0.326**		0.764**	-0.126*	-0.025	-0.184*	0.106	-0.032	0.005
KES	-0.178*	0.178*	0.143*	0.262**	0.259**	0.684**		-0.061	0.004	-0.108	0.125*	-0.012	-0.032
TK	0.014	-0.060	0.065	0.039	0.035	-0.086	-0.156*		-0.273**	0.017	-0.048	0.142*	0.100
LK	0.230**	-0.128*	-0.028	-0.176**	-0.296**	-0.121*	-0.015	-0.284**		0.388**	-0.082	-0.154*	-0.162*
SI	0.239**	-0.130*	0.105	-0.121*	-0.198*	-0.187*	-0.114*	-0.018	0.376**		0.016	-0.190*	-0.358**
MTK	0.014	-0.015	-0.058	-0.035	-0.051	0.082	0.018	-0.003	-0.009	-0.077		-0.130*	0.059
MLK	-0.231**	0.118*	-0.007	0.121*	0.207*	-0.060	-0.061	-0.039	-0.123*	-0.152*	-0.128*		0.521**
MSI	-0.100	0.045	0.052	0.088	0.203*	-0.001	-0.061	0.103	-0.131*	-0.271**	0.052	0.460**	

Notes: * $P<0.05$, ** $P<0.0001$.

Abbreviations: GS, grip strength; BES, back extensor strength; HFS, hip flexor strength; KES, knee extensor strength; TK, thoracic kyphosis angle; LK, lumbar kyphosis angle; SI, sacral inclination; MTK, mobility of the thoracic kyphosis angle; MLK, mobility of the lumbar kyphosis angle; MSI, mobility of the sacral inclination.

Table 5 Factors affecting lumbar kyphosis and spinal inclination in the male and female study participants

Variables	Lumbar kyphosis		Spinal inclination	
	Regression coefficient (95% CI)	P-value	Regression coefficient (95% CI)	P-value
Male				
Age, years	–	–	0.011 (–0.067, 0.090)	0.775
Height, cm	–0.010 (–0.353, 0.153)	0.438	–	–
Body weight, kg	–0.002 (–0.204, 0.200)	0.983	–	–
Grip strength, kg	–	–	0.002 (–0.089, 0.092)	0.971
Back extensor strength, kg	–0.211 (–0.346, –0.076)	0.002	–0.042 (–0.103, 0.018)	0.171
Hip flexor strength, kg	–	–	–0.097 (–0.191, –0.002)	0.045
Thoracic kyphosis angle, degree	–0.219 (–0.308, –0.130)	<0.0001	–	–
Lumbar kyphosis angle, degree	–	–	0.150 (0.102, 0.199)	<0.0001
Female				
Age, years	0.157 (–0.010, 0.325)	0.066	0.087 (0.011, 0.162)	0.025
Height, cm	–0.042 (–0.251, 0.167)	0.691	–0.012 (–0.105, 0.082)	0.807
Body weight, kg	0.027 (–0.232, 0.286)	0.836	0.060 (–0.056, 0.175)	0.310
Grip strength, kg	–0.109 (–0.378, 0.159)	0.424	–0.011 (–0.089, 0.068)	0.791
Back extensor strength, kg	–0.308 (–0.480, –0.136)	0.001	–0.127 (–0.283, –0.030)	0.112
Hip flexor strength, kg	–	–	–0.011 (–0.139, 0.118)	0.870
Thoracic kyphosis angle, degree	–0.191 (–0.260, –0.122)	<0.0001	–	–
Lumbar kyphosis angle, degree	–	–	0.149 (0.101, 0.198)	<0.0001

Note: Results of a multiple regression analysis.

Abbreviation: CI, confidence interval.

Females

A significantly negative correlation between lumbar kyphosis angle and height ($r=-0.128$, $P<0.05$), grip strength ($r=-0.176$, $P<0.0001$), back extensor strength ($r=-0.296$, $P<0.0001$), hip flexor strength ($r=-0.121$, $P<0.05$), and thoracic kyphosis angle ($r=-0.284$, $P<0.0001$) was determined, whereas the correlation of the lumbar kyphosis angle with age ($r=0.230$, $P<0.0001$) and spinal inclination ($r=0.388$, $P<0.0001$) was significantly positive. Spinal inclination correlated positively with age ($r=0.239$, $P<0.0001$) and lumbar kyphosis angle ($r=0.376$, $P<0.0001$) and negatively with height ($r=-0.130$, $P<0.05$), grip strength ($r=-0.121$, $P<0.05$), back extensor strength ($r=-0.198$, $P<0.05$), hip flexor strength ($r=-0.187$, $P<0.05$), and knee extensor strength ($r=-0.114$, $P<0.05$).

Multiple regression analyses

Multiple regression analyses were performed to determine the factors that influenced the lumbar kyphosis angle and spinal inclination in males and females. Variables demonstrating significant correlations with lumbar kyphosis angle and spinal inclination in the univariate analysis were included. The results showed that back extensor strength and thoracic kyphosis angle were significantly associated with the lumbar kyphosis angle in both sexes (Table 5). Hip flexor strength and lumbar kyphosis angle were significantly associated with

spinal inclination in males, whereas in females, the factors significantly associated with spinal inclination were age and the lumbar kyphosis angle (Table 5).

Discussion

This study demonstrated that grip, back extensor, hip flexor, and knee extensor strength decrease significantly in elderly Japanese males and females. The accelerated decline in muscle strength that occurs with aging is well established.^{19,20} This study showed significantly less muscle strength in the upper and lower extremities in individuals in their 80s than in those in their 50s and 60s. Larsson et al²¹ reported that strength of the quadriceps was stable until age 40 years but began to decrease at the age of 50 years. Upper extremity power and strength are reduced by almost 30% in 60-year-old people vs 20-year-old participants.²²

In the group of elderly Japanese examined in this study, back extensor strength declined with age in both sexes, especially among individuals in their 70s and 80s. A previous study determined an approximately 50% decline in lumbar extensor strength between the third and sixth decades of life.¹⁰ Other studies reported a decrease in trunk muscle strength in older adults²³ and that back extensor strength decreases with aging, especially in the already elderly. However, sex-related differences in back extensor strength had not been previously investigated. Our study showed that

back extensor strength decreased significantly with aging and was a significant predictor of lumbar kyphosis in both sexes, suggesting that a decrease in back extensor strength contributes to age-related lumbar kyphotic deformities in both males and females.

We also identified that age-related changes in spinal kyphosis angles, evaluated using the SpinalMouse, differed between sexes. Several studies have demonstrated an inverse correlation between spinal extensor muscle strength and thoracic hyperkyphosis.^{24,25} Among our patients, the decreased back extensor strength and increased thoracic kyphosis were significant factors associated with the lumbar kyphosis angle, both in males and in females. In the lumbar spine, fatty degeneration and volume loss of the paraspinal muscles are associated with degenerative kyphosis.²⁶ The natural aging process affects all elements of the spine, including the intervertebral disks, facet joints, vertebral bodies, and supporting muscles and ligaments.²⁷ Although these additional factors were not evaluated in this study we did find that the decrease in back extensor strength during aging was related to an increase in the lumbar kyphosis angle in both our male and our female participants.

Spinal inclination, which represents the degree of forward positioning of the trunk, increased significantly with age in our study population. In males, the lumbar kyphosis angle was significantly related to the increase in spinal inclination. In females, age, BMI, and lumbar kyphosis angle had a significantly positive relationship, and hip flexor strength a significantly negative relationship, with increased spinal inclination. Previous reports showed an association between spinal inclination and unstable body balance as well as an increased incidence of falls.^{9,28,29} Accordingly, the prevention of increased spinal inclination may contribute to decreasing the risk of falls. Spinal inclination is compensated not only by spinal extension but also by hip extension or knee flexion. In this study, increased hip flexor strength was associated with an increase in spinal inclination in females. Therefore, in this group, strengthening of both the back extensors and the lower extremities could be useful in preventing falls.

There were several limitations in this study. First, even though the *P*-values were <0.05 , the correlation coefficients were weak to moderate, owing to the large sample size. Second, the number of male and female participants in the different age groups was not the same, which may have influenced the statistical analyses.

Conclusion

However, our results suggested significant decreases in grip strength, hip flexor strength, and knee extensor strength

during aging in Japanese males and females. We also found a significant decrease in the lumbar, but not the thoracic, kyphosis angle during aging in females, whereas this was not the case in males. By contrast, spinal inclination increased significantly with aging in both sexes. Back extensor strength and thoracic kyphosis angle were significantly associated with the lumbar kyphosis angle in males and females. In males, the lumbar kyphosis angle and hip flexor strength had a significant effect on spinal inclination, whereas in females, spinal inclination was significantly associated with age and the lumbar kyphosis angle.

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Disclosure

The authors report no conflicts of interest in this work.

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