Studies on sagittal spinal alignment in middle-aged and elderly women and on strength training of lumbar back muscles
（中高齢女性における立位姿勢アライメントと腰背部筋トレーニングに関する研究）

正木　光裕

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主論文１

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Association of sagittal spinal alignment with thickness and echo intensity of lumbar back muscles in middle-aged and elderly women: A Cross-Sectional Study

Authors

Mitsuhiro Masaki[1], Tome Ikezoe[1], Yoshihiro Fukumoto[2], Seigo Minami[3], Rui Tsukagoshi[4], Kaoru Sakuma[1,5], Satoko Ibuki[1], Yosuke Yamada[6], Misaka Kimura[7], Noriaki Ichihashi[1]

[1]Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan

[2]Department of Physical Therapy, Faculty of Rehabilitation, Kobe Gakuin University, Hyogo, Japan.

[3]Department of Occupational Therapy, Faculty of Allied Health Sciences, Yamato University, Osaka, Japan.

[4]Department of Physical Therapy, Faculty of Rehabilitation, Hyogo University of Health Sciences, Hyogo, Japan.

[5]Japan Society for the Promotion of Science, Tokyo, Japan.

[6]Department of Nutritional Science, National Institute of Health and Nutrition, Tokyo, Japan.

[7]Faculty of Bioenvironmental Science, Kyoto Gakuen University, Kyoto, Japan.

Abstract

Objective: Quantitative changes, such as a decrease in muscle mass, and qualitative changes, such as an increase in the amount of intramuscular non-contractile tissue, occur with aging. However, it is unclear whether quantitative or qualitative changes in back muscles are associated with spinal alignment in the standing position. We investigated the association of sagittal spinal alignment with muscle thickness as an index of the mass of lumbar back muscles and muscle echo intensity as an index of the amount of non-contractile tissue within these muscles.

Methods: Study participants comprised 36 middle-aged and elderly women. Thickness and echo intensity of erector spinae, psoas major, and lumbar multifidus muscles were measured using an ultrasound imaging device. Standing sagittal spinal alignment, determined from thoracic kyphosis and lumbar lordosis angles, and the sacral anterior inclination angle was measured using the Spinal Mouse.

Results: Stepwise regression analysis performed using muscle thickness, echo intensity, and age as independent variables showed that erector spinae muscle thickness was a significant determinant of the thoracic kyphosis angle. Psoas major muscle thickness and echo intensity of the lumbar multifidus muscle were significant determinants of the sacral anterior inclination angle.

Conclusion: Our results suggest that an increase in thoracic kyphosis is associated with a decrease in the mass of the erector spinae muscle, and that a decrease in pelvic anterior inclination is associated

with a decrease in the mass of the psoas major muscle and an increase in the amount of non-contractile tissue within the lumbar multifidus muscle.

Key words: aged; middle-aged; paraspinal muscles; posture; ultrasonography

1. Introduction

It is well established that age-related changes in spinal alignment in the standing position such as increased kyphosis (Kado et al., 2013; Takeda et al., 2009) and pelvic posterior inclination (Takeda et al., 2009) occur in middle-aged and elderly women. In fact, 20%–40% of elderly people develop hyperkyphosis, which may be caused by deformity of the vertebral body, degeneration of intervertebral disks, and muscle weakness (Kado, Prenovost, & Crandall, 2007a). Hyperkyphosis leads to a decline in mobility, with effects such as decreased walking speed (Miyazaki et al., 2013; Katzman, Vittinghoff, & Kado., 2011) and falls (Kado et al., 2007b). Therefore, improvement in spinal alignment and prevention of kyphosis progression are important for middle-aged and elderly people, especially in elderly women who have a higher risk of osteoporotic fracture (Swezey., 2000).

Although muscle weakness may contribute to hyperkyphosis alignment in the standing position, a previous study demonstrated no association of trunk flexor strength with lumbar lordosis and sacral anterior inclination angles (Kim et al., 2006). However, it has been revealed that a decrease in trunk extensor strength is associated with thoracic kyphosis and lumbar lordosis angles, and the sacral anterior inclination angle in the standing position (Sinaki et al., 1996). A previous study using computed tomography also indicates that the muscle density of lumbar back muscles including erector spinae and lumbar multifidus muscles is associated with thoracic kyphosis in the elderly individuals (Katzman et al., 2012). These studies suggest that kyphosis progression with aging may

be associated with back muscles rather than abdominal muscles.

It has been verified that muscle thickness (MT) on ultrasound imaging, which is strongly correlated with muscle mass on magnetic resonance imaging (Miyatani et al., 2004), influences muscle strength (Fukumoto et al., 2012). Muscle strength is influenced by not only muscle quantity, such as muscle mass, but also muscle quality, such as the amount of intramuscular non-contractile tissue (i.e., adipose and fibrous tissue). It has been recently demonstrated that muscle echo intensity (EI) on ultrasound imaging, which is utilized as an objective assessment of muscle quality represents the amount of intramuscular non-contractile tissue (Pillen et al., 2009; Reimers et al., 1993). EI of upper and lower extremity muscles increases with aging (Arts., 2010; Ikezoe., 2012a) and these qualitative changes are associated with muscle strength in middle-aged and elderly women (Fukumoto et al., 2012).

With regard to a decrease in back muscle mass, the thickness of psoas major and erector spinae muscles in elderly women who are able to perform activities of daily living independently is lower than that in young women, whereas no difference is observed in the thickness of the lumbar multifidus muscle between the two groups (Ikezoe et al., 2011a,b; Ikezoe et al., 2012b). Thus, many studies investigated the effect of age on atrophy of back muscles. However, there have been few studies focusing on age-related qualitative changes in back muscles (McLoughlin et al., 1994). Furthermore, no study has individually evaluated quantitative or qualitative changes in back muscles,

and examined whether their changes in each back muscle influence sagittal spinal alignment, i.e. thoracic kyphosis and lumbar lordosis angles, and the sacral anterior inclination angle in the standing position, in middle-aged and elderly women.

This study had two aims. First, we investigated the effect of age on MT as an index of the mass of lumbar back muscles and muscle EI as an index of the amount of non-contractile tissue within these muscles using ultrasound. Second, we examined the association of sagittal spinal alignment in the standing position with the thickness and EI of lumbar back muscles in middle-aged and elderly women.

2. Participants and methods

2.1. Participants

Study participants comprised 36 middle-aged and elderly women who were living independently in Kyoto, Japan. The participants were excluded if they had low back pain; a history of orthopedic, neurological, respiratory, or circulatory disorders; previous spinal surgery; or a history of low back pain lasting 3 months or more.

All participants provided written informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine.

2.2. Ultrasound measurement

MT and EI were measured using a B-mode ultrasound imaging device (LOGIQ Book Xp; GE Healthcare Japan, Tokyo, Japan) with an 8-MHz linear array probe. Longitudinal ultrasound images of erector spinae and psoas major muscles and transverse ultrasound images of the lumbar multifidus muscle were taken bilaterally in the prone position (Figure 1). Measurement sites were as follows: erector spinae and psoas major muscles (Ikezoe et al., 2011a,b) were assessed 7 cm lateral from the L3 spinous process, and the lumbar multifidus muscle (Ikezoe et al., 2012b) was assessed 2 cm lateral to the L4 spinous process. A 58-dB gain was used for all muscles, and dynamic focus depth was set to the depth of the muscles. Dynamic range (69 Hz) and time gain compensation in the neutral position were set for measurement.

From the obtained images, EI was determined using image processing software (ImageJ; National Institutes of Health, Bethesda, MD, USA). Regions of interest were set at the depth of 2.0–3.5 cm for the erector spinae muscle, 1.5–2.5 cm for the lumbar multifidus muscle, and 3.5–5.0 cm for the psoas major muscle, avoiding the surrounding fascia. The mean EI of the region was assessed by computer-assisted 8-bit gray-scale analysis and was expressed as a value between 0 (black) and 255 (white). Enhanced EI indicates an increase in the amount of intramuscular fibrous and adipose tissue. The mean values of the thickness and EI for the right and left muscles were used for statistical analyses.

Furthermore, to examine the intrarater reliability of the ultrasound technique for measuring the thickness and EI of erector spinae, lumbar multifidus, and psoas major muscles, two images of each muscle were taken on two separate days in eight healthy volunteers (age, 23.5± 1.5 years).

2.3. Measurement of spinal alignment in the standing position

Standing sagittal spinal alignment (thoracic kyphosis and lumbar lordosis angles, and the sacral anterior inclination angle) was measured using the Spinal Mouse (Index Ltd., Tokyo, Japan). The Spinal Mouse is an electronic computer-aided measuring device that measures intersegmental angles in a non-invasive manner. The Spinal Mouse was guided along the midline of the spine, starting at the spinous processus of C7 and finishing at S3. The thoracic kyphosis angle was calculated from the sum of 11 segmental angles from Th1/2 to Th11/12. The lumbar lordosis angle was calculated from the sum of six segmental angles from Th12/L1 to L5/S1. The sacral anterior inclination angle was calculated from the difference between the sacral angle and the vertical plane. Spinal alignment was measured three times, and the mean value was used for analyses. Previous studies (Kellis et al., 2008; Guermazi et al., 2006) demonstrated a high degree of intrarater reliability and validity for alignment measurement in the standing position using the Spinal Mouse.

2.4. Statistical analyses

Statistical analyses were performed using SPSS version 20.0 (IBM Japan; Tokyo, Japan). Spearman's correlation coefficient was used to investigate the relationship between MI, EI, spinal alignment, and age after each variable was evaluated using Shapiro–Wilk tests. Stepwise regression analysis, using MI, EI, and age as the independent variables, was employed to investigate associations with spinal alignment. The variance inflation factor (VIF) was computed to monitor for a multicollinearity effect. Furthermore, intraclass correlation coefficients [ICCs (1.1)] were calculated to examine intrarater reliabilities of MT and EI measurements. P values of <0.05 were considered significant.

3. Results

Table 1 presents participant characteristics and MT, EI, and spinal alignment measurements in the standing position. In the reliability analysis of MT measurement, ICC (1.1) values were 0.824 for the erector spinae muscle, 0.899 for the lumbar multifidus muscle, and 0.947 for the psoas major muscle. For EI measurement, ICC (1.1) values were 0.894 for the erector spinae muscle, 0.831 for the lumbar multifidus muscle, and 0.664 for the psoas major muscle.

Table 2 lists correlation coefficients between MT, EI, spinal alignment, and age. The lumbar lordosis angle showed a significant negative correlation with age, i.e., the lumbar lordosis angle decreased with age. MT, EI, and thoracic kyphosis and sacral anterior inclination angles were not

significantly correlated with age. Stepwise regression analysis revealed that only the thickness of the erector spinae muscle was a significant and independent determinant of the thoracic kyphosis angle, i.e., the thoracic kyphosis angle increased with a decrease in the thickness of the erector spinae muscle. The VIF value was 1.00. In stepwise regression analysis for the lumbar lordosis angle, no significant variable was found. The thickness of the psoas major muscle and EI of the lumbar multifidus muscle were significant and independent determinants of the sacral anterior inclination angle, i.e., the sacral anterior inclination angle decreased with a decrease in the thickness of the psoas major muscle and an increase in EI of the lumbar multifidus muscle. The VIF value was 1.01 (Table 3).

4. Discussion

Kyphosis progression with aging has been shown to be associated with balance in standing (Choi et al., 2011) and the risk of falling (Kado et al., 2007). However, the association of sagittal spinal alignment with the mass of lumbar back muscles and the amount of non-contractile tissue within these muscles has not been clarified. The present study examined the association of sagittal spinal alignment with MT as an index of the mass of lumbar back muscles and muscle EI as an index of the amount of non-contractile tissue within these muscles in middle-aged and elderly women.

Our results showed that both the thickness and EI of lumbar back muscles were not significantly

correlated with age. Ikezoe et al. (2011a,b; 2012b) demonstrated that the thickness of erector spinae and psoas major muscles in elderly women is lower than that in young women. Our study targeted only middle-aged and elderly women, which may be the reason why no correlation with age was observed.

Stepwise regression analysis showed that the thoracic kyphosis angle increased with a decrease in the thickness of the erector spinae muscle. Antigravity muscles, such as the erector spinae muscle, which are located at the back of kyphosis thoracic vertebrae, play an important role in maintaining posture. Ikezoe et al. (2012b) demonstrated that remarkable atrophy of antigravity muscles occurs in elderly women. Our results suggest that a decrease in the mass of the erector spinae muscle may influence thoracic kyphotic posture in middle-aged and elderly women. However, our result is inconsistent with the result indicating the association between muscle density of lumbar back muscles and thoracic kyphosis in the elderly individuals that previous study (Katzman et al., 2012) has demonstrated. The inconsistency of the results might be influenced by differences in study participants and in methods for measurement i.e. including erector spinae and lumbar multifidus muscles.

Although the lumbar lordosis angle showed a significant negative correlation with age, stepwise regression analysis showed that there was no association between the lumbar lordosis angle and both the thickness and EI of back muscles. Powell et al. (1986) demonstrated that the prevalence of

lumbar disk degeneration reaches approximately 90% in elderly women aged >71 years. Furthermore, a longitudinal study (Takeda et al., 2009) revealed that a decrease in the lumbar lordosis angle is associated with lumbar disk anterior degeneration. Therefore, a decrease in the lumbar lordosis angle may be related to lumbar disk degeneration rather than the mass of lumbar back muscles or the amount of non-contractile tissue within these muscles.

Stepwise regression analysis also showed that the sacral anterior inclination angle decreased with a decrease in the thickness of the psoas major muscle and an increase in EI of the lumbar multifidus muscle. The psoas major muscle is an antigravity postural muscle. Ikezoe et al. (2011a) demonstrated that there is remarkable atrophy of the psoas major muscle in healthy elderly women compared with young women. Our results suggest that age-related atrophy might occur in the psoas major muscle, which may lead to decreased pelvic anterior inclination. The lumbar multifidus muscle also plays an important role in maintaining the upright posture of the pelvis (O'Sullivan et al., 2006). Previous studies (Ikezoe et al., 2012b; McLoughlin et al., 1994) showed that the amount of adipose tissue within the lumbar multifidus muscle increases with aging, whereas the thickness of this muscle does not differ between elderly women who are able to perform activities of daily living independently and young women. Therefore, an age-related change in EI (i.e., an increase in the amount of non-contractile tissue within the lumbar multifidus muscle), which is greater than the change in MT, may lead to decreased pelvic anterior inclination.

The present study has several limitations. One limitation is that our MT and EI measurements targeted only lumbar back muscles. Another limitation is that this study was a cross-sectional study. Hyperkyphotic posture due to deformity of the vertebral body and degeneration of intervertebral disks with aging (Keorochana et al., 2011; Takeda et al., 2009) may lead to inactivity of lumbar back muscles, i.e., may cause changes in the thickness and EI of these muscles. However, it has been reported that strength training for back muscles is effective for improving hyperkyphotic posture (Katzman et al., 2007) or preventing kyphosis progress (Ball et al., 2009) in middle-aged and elderly women. Therefore, we assumed that the changes in the thickness and EI of lumbar back muscles may influence spinal alignment.

5. Conclusions

This study showed that sagittal thoracic and pelvic alignments in the standing position are associated with not only muscle quantity (i.e. muscle size) but also muscle quality (i.e. EI, the amounts of fibrous and adipose tissue within the muscle) of lumbar back muscles.

Conflicts of interest statement

No funding sources and potential conflicts of interest were disclosed for the present study.

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Table 1. Characteristics and muscle thickness, muscle echo intensity, and spinal alignment measurements in healthy middle-aged and elderly female participants.

	Mean ± SD	Range
Characteristics		
Age (years)	72.4 ± 8.0	54.0–91.0
Height (cm)	150.2 ± 4.5	140.1–161.0
Weight (kg)	48.8 ± 7.7	37.4–65.5
MT (cm)		
Erector spinae	2.23 ± 0.48	1.22–3.20
Lumbar multifidus	2.34 ± 0.35	1.29–2.95
Psoas major	1.40 ± 0.40	0.80–2.43
EI		
Erector spinae	71.1 ± 12.1	49.8–101.5
Lumbar multifidus	77.3 ± 7.4	61.5–90.2
Psoas major	41.0 ± 9.7	21.1–60.1
Spinal alignment (°)		
Thoracic kyphosis	36.1 ± 13.7	13.0–86.0
Lumbar lordosis	12.7 ± 7.1	−10.0 to 24.0

Sacral anterior inclination	3.3 ± 5.2	−10.0 to 16.0

MT: muscle thickness, EI: muscle echo intensity, SD: standard deviation

Table 2. Relationships between muscle thickness, muscle echo intensity, spinal alignment, and age.

	Age
Erecter spinae MT	0.07
Lumbar multifidus MT	−0.02
Psoas major MT	−0.14
Erecter spinae EI	−0.09
Lumbar multifidus EI	−0.21
Psoas major EI	0.14
Thoracic kyphosis	−0.16
Lumbar lordosis	−0.34*
Sacral anterior inclination	−0.04

MT: muscle thickness, EI: muscle echo intensity

*$P < 0.05$

Table 3. Results of stepwise regression analyses.

Dependent variables	Independent variables	Partial regression coefficient	Standard partial regression coefficient	*t* value	*P* value	95% Confidence interval	
						Lower	Upper
Thoracic kyphosis							
R^2 = 0.23	MT of Erecter spinae	−13.76	−0.48	−3.22	<0.01	−22.42	−5.09
Sacral anterior inclination							
R^2 = 0.32	MT of psoas major	6.49	0.51	3.49	<0.01	2.71	10.28
	EI of Lumbar multifidus	−0.22	−0.32	−2.21	<0.05	−0.43	−0.02

MT: muscle thickness, EI: muscle echo intensity, R^2: Coefficient of determination

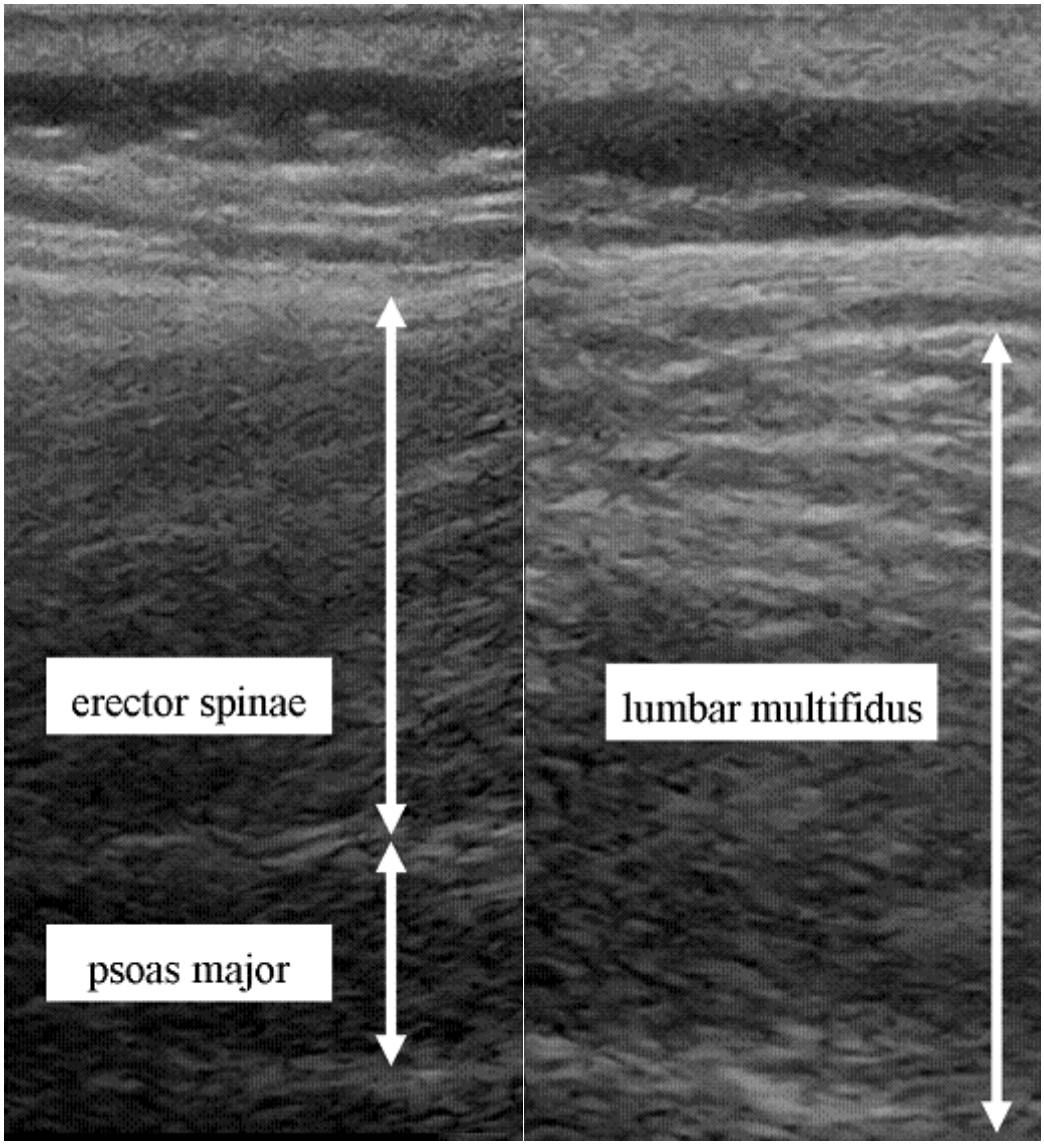

Figure 1. Representative ultrasound images of lumbar back muscles.

主論文２

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Electromyographic analysis of training to selectively strengthen the lumbar multifidus muscle: The effects of different lifting directions and weight loading of the extremities during quadruped upper and lower extremity lifts

Authors

Mitsuhiro Masaki[1], Hiroshige Tateuchi[1], Rui Tsukagoshi[2], Satoko Ibuki[1], Noriaki Ichihashi[1]

[1]Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan

[2]Department of Physical Therapy, Faculty of Rehabilitation, Hyogo University of Health Sciences, Hyogo, Japan.

ABSTRACT

Objectives: The lumbar multifidus muscle (LMF) is a lower back muscle that contributes to spinal stability. Several electromyographic analyses have evaluated LMF activity during various types of training. The present study examined the activity of the back muscles during quadruped upper and lower extremity lifts (QULEL) with different lifting direction and weight loading of extremities.

Methods: Seventeen healthy men were included as subjects. The exercise conditions comprised raising the upper extremity of one side and the lower extremity of the opposite side in a quadruped position with different lifting direction and weight loading. The various combinations of lifts were modifications of conventional QULEL, in which the upper extremity is raised to 180° shoulder flexion and the lower extremity to 0° hip extension. The effects of different lifting directions and weight loading on LMF and lumbar erector spinae muscle (LES) activities were measured using surface electromyography.

Results: The LMF activity and the LMF/LES activity ratio on the side of lower extremity lifting were higher during QULEL with the upper and lower extremities in abduction than during conventional QULEL. The LMF/LES activity ratio was lower during QULEL with weight loading on the upper and lower extremities than during conventional QULEL.

Conclusions: The results of the present study suggest that QULEL with shoulder and hip abduction is more effective to selectively strengthen LMF on the side, where the lower extremity is lifted.

Loading weight onto both the lifted upper and lower extremities during QULEL is disadvantageous as a selective LMF training method because the LMF/LES activity ratio is low.

Key words: aged; electromyography; paraspinal muscles; exercise therapy

INTRODUCTION

The lumbar multifidus muscle (LMF) contributes to spinal stability.[1–3] Several electromyographic analyses have evaluated LMF activity during various types of training.[4–10] Lumbar multifidus muscle atrophy in acute[11,12] and chronic low back pain (LBP) patients has been observed in studies using computed tomography and magnetic resonance imaging images.[13–16] In patients with LBP, the selective atrophy of LMF compared with that of lumbar erector spinae muscle (LES) has been demonstrated,[17] and the proportion of fatty tissue in LMF increases in them.[18,19] Therefore, the importance of effective strengthening of LMF is attracting attention in the rehabilitation of patients with LBP.

Previous studies[20–22] revealed that the activity of LMF, which is a member of the deep muscles of the back, decreases, whereas the activity of LES, which is a member of the superficial muscles of the back, increases in individuals with LBP or those with LBP history (LBPH). Decreased LMF activity causes lumbar spine instability, which may contribute to LBP recurrence.[23] A previous study has also examined the effect of training on the strengthening of lower back muscles in patients with LBP,[24] revealing that selective training of LMF immediately increases LMF activity and decreases LES activity during spinal movement in a standing position compared with training of all lower back muscles (including both LMF and LES). Therefore, training to selectively strengthen LMF is considered to be effective in increasing LMF activity in individuals with LBP or LBPH.

There are various different types for training of the low back muscles including LMF and LES. Quadruped upper and lower extremity lift (QULEL), in which the subject raises the upper extremity on a side and the lower extremity on the other side to a horizontal position in the quadruped position, is known to activate LMS. Ekstrom et al[10] compared the muscle activities during various exercises in healthy subjects and found that QULEL resulted in relatively high activity of the LMF muscle on the side where the lower extremity was lifted (lower extremity side) and that the percent maximum voluntary contraction (MVC) of LMF was higher than that of LES. On the other hand, LMF activity on the side where the upper extremity was lifted (upper extremity side) was lower than LES activity. Therefore, it is considered that QULEL is an adequate exercise to selectively activate the LMF muscle on the lower extremity side. However, because the muscle activity was expressed as percent MVC in their study, the selectivity of the muscle activity among exercises cannot be compared.

Therefore, the purpose of this study was to identify a method to train the LMF muscle more selectively and strongly. This study examined the effect of modifying a specific exercise by adding rotation moment of the spine by changing the direction of lifting upper and lower extremities and weight loading of the extremities. In addition, to estimate the selectivity, we examined the activity ratio of LMF and LES (LMF/LES activity ratio). The muscle activity ratio has been calculated in some studies examining the activity of the shoulder girdle[25,26] or the scapular[27] muscles. However, to our knowledge, this is the first study to examine the activities of LMF and LES in terms of the

activity ratio.

METHODS

Participants

The subjects comprised 17 healthy young men (age 22.4 ± 1.3 years, height 173.1 ± 5.7cm, weight 65.5 ± 11.7 kg). All subjects were volunteers recruited from Kyoto University. Individuals with musculoskeletal conditions or those with neurological or cardiovascular disorders that would limit their ability to perform the exercises were excluded. All subjects provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine.

Experimental procedure

The experiment was broadly divided into two parts: lifting extremities in (a) different directions and with (b) different weight loading. Conventional QULEL is performed by lifting the right upper and the left lower extremities to a horizontal position. In the present study, variants of conventional QULEL were performed in which the extremities were lifted in different directions as follows (Figure 1): (1) right upper extremity lifted to 180° shoulder flexion and left lower extremity lifted to 0° hip extension (F–E), (2) right upper extremity lifted to 90° shoulder abduction and left lower

extremity lifted to 0° hip extension (A–E), (3) right upper extremity lifted to 180° shoulder flexion and left lower extremity lifted to maximum hip abduction (F–A), and (4) right upper extremity lifted to 90° shoulder abduction and left lower extremity lifted to maximum hip abduction (A–A). The exercise conditions with different weight loading of the lifted extremities were further divided as follows (Figure 1): (1) F–E (2) F–E with a weight belt weighing 2.5% of the body weight attached to the right wrist (BW; F2.5–E), (3) F–E with a weight belt weighing 5.0% of BW (F–E5) attached to the left ankle, and (4) F–E with a weight belt weighing 2.5% of BW attached to the right wrist, and weight belt weighing 5.0% of BW attached to the left ankle (F2.5–E5).

Exercises were assigned in a random order to each subject. Each exercise was performed thrice, with adequate rest periods between the different exercises.

Electromyography (EMG) recording and data analysis

EMG data were collected by sampling at 1500 Hz, using the Telemyo 2400T (Noraxon USA; Scottsdale, AZ, USA). After the electrode sites were cleaned with a scrubbing gel and washed with alcohol, bipolar surface electrodes (Ambu; Baltorpbakken, Denmark) with a 2-cm center-to-center inter-electrode distance were applied to the four muscles: LMF (at the level of the L5 spinous process on a line extending from the posterior superior iliac spine to the interspace between L1 and L2)[28] bilaterally and LES (4-cm lateral to the L1 spinous process)[10] bilaterally. The ground electrode

was affixed to the skin over the iliac crest. In each exercise, the EMG signals were measured for 3 seconds, after the subjects raised their extremities and were able to maintain a stable position. The original raw EMG signals were bandpass filtered at 10–500 Hz, and the root-mean-square amplitude of the signals was computed using 50-millsecond windows. Electromyography values of each muscle were then expressed as percentages of the EMG values during MVCs. The EMG signals during the stable 3-second period were recorded as MVCs for each muscle. Furthermore, the LMF/LES activity ratio, which shows the selective strengthening of LMF compared with that of LES, was calculated.

Statistical analysis

The sample size required for the present study was calculated utilizing G*Power software version 3.1.9.2 (Franz Faul, University of Kiel, Kiel, Germany). Results indicated that 10 subjects would provide a statistical power of 0.80 and an effect size of 0.40 for analysis of variance.

Statistical analyses were performed using SPSS version 20.0 (IBM Japan; Tokyo, Japan). Lumbar multifidus muscle activity, LES activity, and the LMF/LES activity ratio in both the upper extremity and lower extremity sides were measured and compared in the exercise conditions with different directions (F–E, A–E, F–A, and A–A) and different weight loading (F–E, F2.5–E, F–E5, and F2.5–E5). After EMG variables were examined using Shapiro–Wilk tests, differences in the

variables were evaluated using repeated-measures analysis of variance or Friedman tests. If a significant primary effect was found, the differences were determined by post hoc Bonferroni or Bonferroni correction test for multiple comparisons. P values of < .05 were considered statistically significant.

RESULTS

Effects of lifting direction

There was a significant primary effect on LMF and LES muscle activities and the LMF/LES activity ratio in both the upper and lower extremity sides (Table 1).

On the upper extremity side, LMF activity during the F–A and A–A conditions was significantly lower than that during the F–E condition. LES activity during the A–A condition was significantly lower than that during the F–E condition.

On the lower extremity side, LMF activity during the F–A and A–A conditions was significantly higher than that during the F–E condition. There was no significant difference in LES activity between the F–E and A–A conditions. The LMF/LES activity ratio during the A–A condition was significantly higher than that during the F–E condition.

Effects of weight loading

There was a significant primary effect in LMF and LES activities in both the upper and lower extremity sides (Table 2). A significant effect was also observed in the LMF/LES activity ratio on the lower extremity side only.

On the upper and lower extremity sides, LMF and LES activities during the F2.5–E, F–E5, and F2.5–E5 conditions were significantly higher than that during the F–E condition. However, the LMF/LES activity ratio during the F2.5–E5 condition was significantly lower than that during the F–E condition on the lower extremity side.

DISCUSSION

The present study examined the effects of different lifting directions and weight loading of the extremities during QULEL to clarify effective methods that can selectively strengthen LMF.

Analyses with different lifting directions revealed that LMF activity in both the upper and lower extremity sides were influenced by hip abduction, as observed in the F–A and A–A conditions. Compared with the F–E condition, LMF activity on the lower extremity side was higher, whereas that on the upper extremity side were lower, in these conditions. However, shoulder abduction did not influence LMF activity on either side, and there was no significant difference in LMF activity between the F–E and A–E conditions. A previous study showed that, during QULEL in the F–E condition, LMF activity on the lower extremity side was higher than LES activity.[10] This is because

the weight of the lifted upper and lower extremities contributes to the rotation moment of the spine, relative to the pelvis, toward the lower extremity side, that is, the ipsilateral rotation moment to the lower extremity side increases. Therefore, LMF activity contributing to the contralateral rotation of the spine increases on the lower extremity side. Hip abduction during QULEL affects both the flexion and rotation moments of the spine. It is assumed that the flexion moment of the spine caused by the weight of the lifted lower extremity decreases because the flexion moment arm of the spine, caused by the weight of the lifted lower extremity, decreases with hip abduction. Therefore, LMF activity that results in spinal extension is considered to decrease with a decrease in the flexion moment of the spine on the lower extremity side. On the other hand, the rotation moment arm and the rotation moment of the spine toward the lower extremity side, that is, ipsilateral rotation moment of the lower extremity side, increases with hip abduction and therefore would lead to increased LMF activity.

Lumbar erector spinae activity has been shown to be higher than LMF activity on the upper extremity side during QULEL in the F–E condition.[10] This is probably because the rotation moment of the spine toward the lower extremity side, caused by the weight of the lifted upper and lower extremities (contralateral rotation moment to the upper extremity side), increases when the upper and lower extremities are lifted. The increase in rotation moment contributes to an increase in LES activity, resulting in the ipsilateral rotation of the spine to the upper extremity side. In the present

study, LES activity on the upper extremity side was significantly lower during the A–A condition than during the F–E condition, whereas there was no such difference on the lower extremity side. Hip and shoulder abduction would decrease LES activity, resulting in spinal extension on the upper extremity side. This is because the flexion moment of the spine resulting from the weight of the lifted upper and lower extremities decreases with shoulder and hip abduction. A magnetic resonance imaging study has documented that LES acts on the long extension moment arm of the spine,[29] and it is assumed that it greatly contributes to the generation of spinal extension torque.

The fact that the LMF/LES activity ratio on the lower extremity side increased to a greater degree during the A–A condition than during the F–E condition is also noteworthy. However, there was no significant difference in the LMF/LES activity ratio on the upper extremity side between the F–E and A–A conditions. It is assumed that the increased LMF/LES activity ratio on the lower extremity side is related to increased LMF activity and unchanged LES activity. Therefore, the A–A condition is effective in selectively strengthening LMF.

Furthermore, LMF activity on both sides increased with weight loading compared with that during the F–E condition. The increase in LES activity was similar to that in LMF activity. It is assumed that the flexion moment of the spine increased because of the weight belts added to the original weight of the lifted upper and lower extremities, and LMF and LES activities that result in the extension of the spine increased to maintain the position.

The LMF/LES activity ratio on the lower extremity side decreased, when weight was loaded onto the lifted upper and lower extremities compared with that during the F–E condition. However, no change in the LMF/LES ratio was observed on the upper extremity side between weight loading conditions and the F–E condition. This was probably because the increase in LES activity was greater than that in LMF activity on the lower extremity side, although LMF and LES activities increased in both sides. Therefore, our results suggest that weight loading of the lifted upper and lower extremities during QULEL is disadvantageous for selective LMF training, although it may be effective in cases where it is desirable to globally increase LMF and LES activities.

LIMITATIONS AND FUTURE STUDIES

The present study has several limitations. First, the present study was performed in healthy subjects. It is unclear whether the muscle activity pattern of patients with LBP and individuals with LBPH, who may have altered back muscle activity, will show patterns similar to that observed in the present study. Second, it is unclear how the intervertebral joints and disks are loaded during these exercises in patients with unilateral LBP and individuals with unilateral LBPH who have intervertebral joint and disk degeneration. Previous studies have demonstrated that the changes in lower back and abdominal muscle activities induced a change in anteroposterior joint shear force at the lumbar intervertebral joint and intervertebral compression force during movement.[7,30] These

findings suggest that loads at the intervertebral joints and disks during training may be altered by the change in back muscle activity. In the present study, LMF and LES activities changed because of the difference in the lifting direction of the extremities and loading weight onto the extremities. However, the shear force of the intervertebral joint and the compression force on the intervertebral disk were not measured. Thus, we propose that consideration of these factors is necessary, when these subjects perform the training exercises in the present study.

In the future, intervention studies are required to investigate immediate and long-term changes in the activity pattern of back muscles during movement in the standing position in patients with LBP and LBPH using the training methods that were examined in the present study. Such an investigation will contribute to the establishment of effective training techniques for patients with LBP and individuals with LBPH.

CONCLUSION

The results of the present study suggest that QULEL with shoulder and hip abduction is more effective to selectively strengthen LMF on the side, where the lower extremity is lifted. Loading weight onto both the lifted upper and lower extremities during QULEL is disadvantageous as a selective LMF training method because the LMF/LES activity ratio is low.

FUNDING SOURCES AND POTENTIAL CONFLICTS OF INTEREST

No funding sources or conflicts of interest are reported for the present study.

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Table 1. Lumbar multifidus and LES muscle activities (%MVC) and the LMF/LES muscle activity ratio in exercise conditions, where the extremities were lifted in different directions.

	F–E	A–E	F–A	A–A
The upper extremity side				
LMF	19.3 ± 5.8	16.7 ± 4.9	12.6 ± 4.7[a,b]	11.3 ± 3.8[a,b]
LES	22.5 ± 6.6	19.4 ± 6.3[a]	19.4 ± 5.7[a]	15.4 ± 4.7[a,b,c]
LMF/LES activity ratio	0.89 ± 0.29	0.88 ± 0.22	0.66 ± 0.21[a,b]	0.75 ± 0.24[b]
The lower extremity side				
LMF	28.5 ± 10.0	28.2 ± 9.3	34.1 ± 8.4[a,b]	33.1 ± 8.0[a,b]
LES	15.1 ± 7.4	12.5 ± 5.2	16.2 ± 7.7[b]	14.5 ± 6.2
LMF/LES activity ratio	2.21 ± 1.09	2.56 ± 1.12	2.64 ± 1.43	2.75 ± 1.37[a]

A–A, right 90° shoulder abduction and left maximal hip abduction; A–E, right 90° shoulder abduction and left 0° hip extension; F–A, right 180° shoulder flexion and left maximal hip abduction; F–E, right 180° shoulder flexion and left 0° hip extension; LES, lumbar erector spinae muscle; LMF, lumbar multifidus muscle.

[a] significantly different from F–E ($P < .05$).

[b] significantly different from A–E ($P < .05$).

[c] significantly different from F–A ($P < .05$).

Table 2. Lumbar multifidus and LES muscle activities (%MVC) and the LMF/LES muscle activity ratio in exercise conditions, where weight was loaded onto the lifted extremities.

	F–E	F2.5–E	F–E5	F2.5–E5
The upper extremity side				
LMF	19.3 ± 5.8	25.5 ± 6.8[a]	23.8 ± 8.5[a]	27.2 ± 8.6[a]
LES	22.5 ± 6.6	28.6 ± 8.7[a]	26.8 ± 8.5[a]	31.5 ± 9.7[a,c]
LMF/LES activity ratio	0.89 ± 0.29	0.92 ± 0.17	0.89 ± 0.24	0.88 ± 0.21
The lower extremity side				
LMF	28.5 ± 10.0	32.9 ± 10.2[a]	33.8 ± 13.1[a]	38.6 ± 14.5[a,b,c]
LES	15.1 ± 7.4	19.0 ± 7.0[a]	21.6 ± 10.5[a]	24.7 ± 9.8[a,b]
LMF/LES activity ratio	2.21 ± 1.09	1.81 ± 0.50	1.79 ± 0.74	1.68 ± 0.55[a]

F–E, Right 180° shoulder flexion and left 0° hip extension; F–E5, F–E with load weighing 5.0% of BW on the left ankle; F2.5–E, F–E with load weighing 2.5% of body weight (BW) on the right wrist, F2.5–E5: F–E with load weighing 2.5% of BW on the right wrist and load weighing 5.0% of BW on the left ankle; LES, lumbar erector spinae muscle; LMF, lumbar multifidus muscle.

[a] significantly different from F–E ($P < .05$).

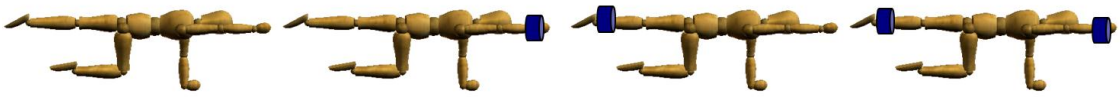
[b] significantly different from F2.5–E ($P < .05$).

[c] significantly different from F–E5 ($P < .05$).

(a) Exercise conditions where the extremities were lifted in different directions

Right 180° shoulder flexion and left 0° hip extension	Right 90° shoulder abduction and left 0° hip extension	Right 180° shoulder flexion and left maximal hip abduction	Right 90° shoulder abduction and left maximal hip abduction
(F–E)	(A–E)	(F–A)	(A–A)

(b) Exercise conditions where weight was loaded onto the lifted extremities



Right 180° shoulder flexion and left 0° hip extension	F-E with load weighing 2.5% of the body weight (BW) on the right wrist	F–E with load weighing 5.0% of BW on the left ankle	F–E with load weighing 2.5% of BW on the right wrist and load weighing 5.0% of BW on the left ankle
(F–E)	(F2.5–E)	(F–E5)	(F2.5–E5)

Fig 1. Variants of conventional QULELs with the extremities lifted in different directions (A) and with different weight loading (B).

参考論文１

Aging Clinical and Experimental Research

平成２７年掲載予定

Association of walking speed with sagittal spinal alignment, muscke thickness, and echo intensity of lumbar back muscles in middle-aged and elderly women

Authors

Mitsuhiro Masaki[1], Tome Ikezoe[1], Yoshihiro Fukumoto[2], Seigo Minami[3], Junichi Aoyama[4], Satoko Ibuki[1], Misaka Kimura[5], and Noriaki Ichihashi[1]

[1]Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan.

[2]Department of Physical Therapy, Faculty of Rehabilitation, Kobe Gakuin University, Hyogo, Japan.

[3]Department of Occupational Therapy, Faculty of Allied Health Sciences, Yamato University, Osaka, Japan.

[4]Department of Rehabilitation, Kyoto Yawata Hospital, Kyoto, Japan.

[5]Faculty of Health and Medical Science, Kyoto Gakuen University, Kyoto, Japan.

Abstract

Background Age-related change of spinal alignment in the standing position is known to be associated with decreases in walking speed, and alteration in muscle quantity (i.e. muscle mass) and muscle quality (i.e. increases in the amount of intramuscular non-contractile tissue) of lumbar back muscles. Additionally, the lumbar lordosis angle in the standing position is associated with walking speed, independent of lower-extremity muscle strength, in elderly individuals. However, it is unclear whether spinal alignment in the standing position is associated with walking speed in the elderly, independent of trunk muscle quantity and quality. The present study investigated the association of usual and maximum walking speed with age, sagittal spinal alignment in the standing position, muscle quantity measured as thickness, and quality measured as echo intensity of lumbar muscles in 35 middle-aged and elderly women.

Methods Sagittal spinal alignment in the standing position, (thoracic kyphosis, lumbar lordosis, and sacral anterior inclination angle) using a spinal mouse, and muscle thickness and echo intensity of the lumbar muscles (erector spinae, psoas major, and lumbar multifidus) using an ultrasound imaging device were also measured.

Results Stepwise regression analysis showed that only age was a significant determinant of usual walking speed. The thickness of the lumbar erector spinae muscle was a significant, independent determinant of maximal walking speed.

Conclusions The results of this study suggest that a decrease in maximal walking speed is associated with the decrease in lumbar erector spinae muscles thickness rather than spinal alignment in the standing position in middle-aged and elderly women.

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Key words: aged; middle-aged; walking speed; posture; paraspinal muscles; ultrasonography

Introduction

Walking speed decreases with aging [1], which leads to a decline of daily activities [2], falls [3], and survival prognosis [4]. Therefore, it is important to identify the risk factors of decreased walking speed to prevent the decline of walking ability in elderly individuals.

Sagittal spinal alignment in the standing position also changes with age-related increased kyphosis [5,6] and pelvic posterior inclination [5]. It has been demonstrated that changes of spinal alignment in the standing position is associated with a decrease in trunk extensor strength [7], but not with trunk flexor strength [8], in middle-aged and elderly women. Thus, previous studies suggested that age-related changes of spinal alignment in the standing position may be associated with back muscles rather than abdominal muscles.

Recently, it was determined that muscle quantity or muscle mass can be assessed from muscle thickness (MT) [9] using a non-invasive ultrasound imaging device. A non-invasive ultrasound imaging device is plausible for use in muscle thickness measurements to estimate muscle mass and in muscle echo intensity (EI) measurements to estimate the amount of intramuscular non-contractile tissue [10,11] (i.e., adipose and fibrous tissue). It has been verified that muscle mass and the amount of intramuscular non-contractile tissue on ultrasound imaging are associated with muscle strength in middle-aged and elderly women [12]. Furthermore, our previous study [13] using an ultrasound imaging device has demonstrated that an increase in thoracic kyphosis in the standing position is

associated with a decrease in the mass of the lumbar erector spinae muscle. Our study also has demonstrated that an increase in pelvic posterior inclination is associated with a decrease in the mass of the psoas major muscle and an increase in the amount of non-contractile tissue within the lumbar multifidus muscle.

It has been demonstrated that age-related decreases in the lumbar lordosis angle and decreases in lower-extremity muscle strength, such as knee extensor strength, are both independent variables associated with decreases in maximal walking speed in elderly individuals [14]. However, there have been no studies that have focused on whether spinal alignment in the standing position and trunk muscle quantity and quality are independently associated with walking speed. Therefore, it is unclear whether spinal alignment in the standing position, such as increased kyphosis and pelvic posterior inclination, or quantitative and qualitative changes in lumbar back muscles, such as decreases in muscle mass and increases in the amount of non-contractile tissue, influence walking speed in elderly individuals. Furthermore, it is also unclear which quantitative or qualitative change in individual muscles of lumbar back muscles are associated with decreased walking speed.

Therefore, the aims of present study are to investigate the association of walking speed with sagittal spinal alignment in the standing position, muscle mass, and the amount of non-contractile tissue of lumbar back muscles measured using an ultrasound imaging device in middle-aged and elderly women.

Materials and methods

Participants

The subjects were 35 healthy middle-aged and elderly women (mean age = 72.9 ± 7.4 years) who were living independently in Kyoto, Japan. The subjects' characteristics are presented in Table 1. Participants were excluded if they had ongoing low back pain or a history of low back pain lasting 3 months or more in the past; orthopedic, neurological, respiratory, or circulatory disorders; or previous spinal surgery.

The protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine. All participants provided written informed consent.

Measurement of walking speed

The usual and maximal walking speeds were determined over a 6-meter distance. Participants were provided with 2 m to accelerate and decelerate before and after the test distance. The walking time of the 6-m distance was recorded using a stopwatch, and walking speed (m/s) was calculated. The participants were not allowed to use canes or walkers.

Measurement of spinal alignment in the standing position

Sagittal spinal alignment in the standing position (thoracic kyphosis, lumbar lordosis, and sacral anterior inclination angle) was measured using the Spinal Mouse (Index Ltd., Tokyo, Japan), based on a previous study [13]. The Spinal Mouse was guided along the midline of the spine, starting at the C7 spinous process and finishing at S3. The thoracic kyphosis angle was calculated from the sum of 11 segmental angles from Th1/2 to Th11/12. The lumbar lordosis angle was calculated from the sum of six segmental angles from Th12/L1 to L5/S1. The sacral anterior inclination angle was calculated from the difference between the sacral angle and the vertical plane. Spinal alignment was measured three times, and the mean value was used for analyses.

Ultrasound measurement

MT and EI were measured to evaluate muscle mass and the amount of intramuscular non-contractile tissue, respectively. MT and EI of lumbar back muscles were measured using a B-mode ultrasound imaging device (LOGIQ Book Xp; GE Healthcare Japan, Tokyo, Japan) with an 8-MHz linear array probe, as described previously [13]. Longitudinal ultrasound images of the lumbar erector spinae and psoas major muscles and transverse ultrasound images of the lumbar multifidus muscle were taken bilaterally in the prone position. The measurement sites were defined as 7 cm lateral from the L3 spinous process for the lumbar erector spinae and psoas major muscles, and 2 cm lateral to the L4 spinous process for the lumbar multifidus muscle. A 58-dB gain, 69-Hz dynamic range, and time

gain compensation with the neutral position were used for all measurements of lumbar back muscles. Dynamic focus depth was set to the depth of the lumbar back muscles.

From the obtained images, EI was determined using image processing software (ImageJ; National Institutes of Health, Bethesda, MD, USA). Regions of interest were set at a depth of 2.0–3.5 cm for the lumbar erector spinae muscle, 1.5–2.5 cm for the lumbar multifidus muscle, and 3.5–5.0 cm for the psoas major muscle, avoiding the surrounding fascia.

The mean EI of the region was assessed by computer-assisted 8-bit gray-scale analysis and was expressed as a value between 0 (black) and 255 (white). Enhanced EI indicated an increase in the amount of intramuscular non-contractile tissue (i.e., adipose and fibrous tissue) within the muscle. The mean values of the thickness and EI for the right and left muscles were used for analyses.

A previous study has shown a high degree of intrarater reliability of the ultrasound technique for measuring the MT and EI of lumbar back muscles [13].

Statistical analyses

Statistical analyses were performed using SPSS version 17.0 (IBM Japan; Tokyo, Japan). Partial correlations between usual and maximal walking speeds and spinal alignment, MT, and EI with age as a control variable were investigated after normality of the variable was evaluated using Shapiro–Wilk tests. Stepwise regression analysis was employed to investigate the associations with

walking speed, using spinal alignment in the standing position, MT, EI, and age as the independent variables. The variance inflation factor (VIF) was examined to monitor for a multicollinearity effect. *P* values of <0.05 were considered significant.

Results

Results of walking speeds, spinal alignment in the standing position, MT, and EI are presented in Table 1.

Table 2 indicates the partial correlation coefficients between walking speed and spinal alignment, MT, and EI with age as a control variable. Usual walking speed showed no significant correlations with any of variables. Maximal walking speed showed a significant positive correlation with the thickness of the lumbar erector spinae muscle, i.e., maximal walking speed decreased with decreased thickness of the lumbar erector spinae muscle.

Stepwise regression analysis revealed that only age was a significant and independent determinant of usual walking speed, i.e., usual walking speed decreased with aging. The VIF value was 1.00, which had no multicollinearity effect in a regression equation. In the stepwise regression analysis for maximal walking speed, only the thickness of the lumbar erector spinae muscle was a significant and independent determinant, i.e., maximal walking speed decreased with a decrease in the thickness of the lumbar erector spinae muscle. The VIF value was 1.01, which had no multicollinearity effect

(Table 3).

Discussion

Investigating the risk factors of decreased walking speed is important for preventing a decline of walking ability in middle-aged and elderly individuals. To the best of our knowledge, this is the first study examining whether spinal alignment in the standing position and MT or EI of lumbar back muscles are independent variables for walking speed. It is also the first study clarifying whether spinal alignment in the standing position, or MT or EI of lumbar back muscles have greater influence on walking speed in middle-aged and elderly women.

As a result of having examined the factors associated with walking speed, stepwise regression analysis showed that usual walking speed decreased with aging, and that maximal walking speed decreased with a decrease in the thickness of the lumbar erector spinae muscle. Chiu et al. [15] has demonstrated that changes in electromyographic activities in the lumbar spinae, biceps femoris, and medial gastrocnemius muscles showed a marked increase with an increase in walking speed. Anders et al [16] has also demonstrated that the electromyography (EMG) of the lumbar erector spinae muscle changed in activity amplitude, but not in activity pattern, with an increase in walking speed in healthy subjects. Furthermore, Thorstensson et al. [17] has documented with electromyographic analysis that the main function of the lumbar erector spinae muscle is to restrict excessive trunk

movements during walking. The erector spinae muscle may be important in controlling the sagittal and frontal movements on the trunk dynamically during walking, because this muscle has a large moment arm of extension and lateral flexion on the spine [18]. The present study showed the association of the thickness of the lumbar erector spinae muscle with maximal walking speed, not with usual walking speed. This is probably because more swift control of trunk movement is required for maximal walking compared with usual walking.

The present study showed that the thickness of the lumbar multifidus muscle was not associated either with usual or maximal walking speeds. The deep muscles of the back such as the lumbar multifidus muscle contribute to lumbar spine stability [19–21]. It has been demonstrated that the EMG activity of the lumbar multifidus muscle increased with an increase in walking speed in healthy subjects [16,22], which suggests that the lumbar multifidus muscle has an important role in walking. However, in a previous study [23] examining age-related changes of the back muscles using an ultrasound imaging device in elderly women who were able to perform activities of daily living independently, an age-related atrophy was observed in the erector spinae muscle, but not in the multifidus muscle. Therefore, the lumbar multifidus muscle might not be associated with walking speed due to its lesser age-related atrophy.

In addition to the lumbar multifidus muscle, the psoas major muscle also contributes to lumbar spine stability [24–26]. The psoas major muscle is known to show a marked age-related atrophy [27].

Although the EMG activity of the psoas major muscle increases with an increase in walking speed [28], the thickness of the psoas major muscle has shown no difference between elderly women who were able to walk at a maximum walking speed of more than 1 m/s and elderly women who were not able to walk fast [29]. These previous studies suggest that despite the remarkable age-related atrophy observed in the psoas major muscle, there is only a minor influence of its muscle mass on walking speed among elderly individuals. Therefore, it is confirmed that no correlation was observed between the thickness of the psoas major muscle and walking speed in this study.

In our study, there was no significant association between walking speed and EI in either of the lumbar back muscles, which suggests that walking speed may be influenced by age-related decreases in muscle mass rather than age-related increases in the amount of intramuscular non-contractile tissue within lumbar back muscles.

Furthermore, our results showed that there was no association between maximal walking speed and spinal alignment in the standing position, which is inconsistent with the results of a previous study [14] indicating the association between maximal walking speed and lumbar lordosis angle in elderly individuals. The inconsistency of these results might be influenced by the small sample size in our study.

The present study had several limitations. First, the measurements of MT and EI targeted only the lumbar back muscles. Second, we did not measure muscle strength in the lower extremities, such as

knee extensor strength, which is known to be associated with walking speed in elderly individuals. Third, the amount of age-related change in spinal alignment, such as increased kyphosis, was slight in the participants of our study. Further studies are required to clarify the association of walking speed with spinal alignment in the standing position, and quantity and quality of lumbar back muscles in middle-aged and elderly women who have increased kyphosis.

The present study suggests that resistance training targeting the lumbar erector spinae muscles may be important to improve maximal walking speed in middle-aged and elderly women. It has been demonstrated that resistance training on lower extremities was effective for improving walking speed in elderly individuals [30, 31]. However, the effect of resistance training of trunk muscles on walking speed in elderly individuals is unclear. Further study is needed to clarify whether improvement in quantity and quality of the trunk muscles, especially lumbar back muscles, leads to improvement in walking speed for middle-aged and elderly women.

Conclusions

The results of the present study suggest that maximal walking speed is associated with the mass of the lumbar erector spinae muscles rather than spinal alignment in the standing position or age-related increases in the amount of intramuscular non-contractile tissue within lumbar back muscles in middle-aged and elderly women.

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Compliance with ethical standards

Funding No funding sources were disclosed for the study.

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Table 1. Subject characteristics.

	Mean ± SD	Range
Age (years)	72.9±7.4	56.0-91.0
Height (cm)	149.9±4.2	140.1-160.8
Weight (kg)	48.6±7.7	37.4-65.5
Walking speed		
Usual walking speed (m/s)	1.70±0.26	1.18-2.34
Maximal walking speed (m/s)	2.14±0.38	1.43-3.64
Spinal alignment (°)		
Thoracic kyphosis	35.9±13.8	13.0-86.0
Lumbar lordosis	12.9±7.1	-10.0-24.0
Sacral anterior inclination	3.3±5.3	-10.0-16.0
MT (cm)		
Lumbar erector spinae	2.25±0.48	1.22-3.20
Lumbar multifidus	2.33±0.35	1.29-2.95
Psoas major	1.41±0.41	0.80-2.43
EI (0-255)		
Lumbar erector spinae	71.0±12.3	49.8-101.5

Lumbar multifidus	77.4±7.5	61.5-90.2
Psoas major	41.2±9.8	21.1-60.1

MT: muscle thickness, EI: muscle echo intensity, SD: standard deviation

Table 2. Partial correlations between walking speed and spinal alignment in the standing position, muscle thickness, and muscle echo intensity with age as a control variable.

	Thoracic kyphosis	Lumbar lordosis	Sacral anterior inclination	Lumbar erector spinae MT	Lumbar multifidus MT	Psoas major MT	Lumbar erector spinae EI	Lumbar multifidus EI	Psoas major EI
Usual walking speed	-0.21	0.18	0.002	0.32	0.13	0.26	0.06	0.09	0.02
Maximal walking speed	-0.22	0.17	0.21	0.42*	0.18	0.33	0.10	-0.009	-0.30

MT: muscle thickness, EI: muscle echo intensity

*$P < 0.05$

Table 3. Results of stepwise regression analyses.

Dependent variables	Independent variables	Partial regression coefficient	Standard partial regression coefficient	*t* value	*P* value	95% Confidence interval	
						Lower	Upper
Usual walking speed							
R^2=0.24	Age	- 0.02	- 0.49	- 3.19	<0.01	- 0.03	- 0.01
Maximal walking speed							
R^2=0.19	MT of Erector spinae	0.35	0.43	2.74	<0.01	0.09	0.60

MT: muscle thickness, R^2: Coefficient of determination

主論文１

Association of sagittal spinal alignment with thickness and echo intensity of lumbar back muscles in middle-aged and elderly women: A Cross-Sectional Study

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主論文２

Electromyographic analysis of training to selectively strengthen the lumbar multifidus muscle: The effects of different lifting directions and weight loading of the extremities during quadruped upper and lower extremity lifts

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