

Relationship of total sagittal spinal alignment index of thoracic kyphosis and lumbar lordosis with physical function in community-dwelling older adults

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ABSTRACT

Background: Overall spinal curvature is evaluated by calculating the difference between the angles of lumbar lordosis (LL) and thoracic kyphosis (TK) and is expressed as LL minus TK (LL-TK). It is unclear whether LL-TK is associated with physical function in community-dwelling older adults and whether it is more relevant than TK or LL alone.

Objective: This study aimed to identify whether LL-TK is associated with physical function in community-dwelling older adults, and whether it is strongly associated than TK or LL alone.

Methods: The participants comprised 1,674 community-dwelling older adults who underwent physical assessments (women, $n=1,099$; mean age, 67.4 ± 5.3 years). As spinal alignment indices, TK and LL were measured using skin surface methods, and LL-TK was calculated as the difference between them. Decreased LL-TK indicated increased overall spinal curvature. Physical function was determined by measuring single-leg standing, five-times chair-stand, and usual gait speed. Stepwise multiple regression analyses were performed with each physical function as the dependent variable and spinal alignment indices as the independent variables, with adjustments.

Results: Multiple regression analyses showed that single-leg standing ($\beta=0.092$, 95% confidence interval [CI]=0.071 to 0.214, $p<0.001$) and five-times chair-stand ($\beta=-0.142$, 95% CI=-0.037 to -0.019, $p<0.001$) were significantly associated with LL-TK, but not LL. Both LL-TK ($\beta=0.121$, 95% CI=0.001 to 0.004, $p<0.001$) and LL ($\beta=0.087$, 95% CI=0.001 to 0.003, $p=0.003$) were significant determinants of usual gait speed.

Conclusions: This study showed that decreased LL-TK may be associated with poor physical function. This association may be stronger than that observed for TK or LL alone.

Keywords: thoracolumbar curvature; kyphosis posture; single-leg standing; five-times chair-stand; usual gait speed

INTRODUCTION

The global older adult population is increasing rapidly, and by 2050, the number of people aged 60 years and older is expected to reach 21% of the world's population (WHO, 2023). The physiological process of aging causes structural changes and functional decline of the musculoskeletal system, leading to difficulty when performing activities of daily living (Frontera et al, 2000). In an aging society, increased medical costs and demand for nursing care are becoming social problems, therefore, it is

important to maintain independent living among older adults by preventing the decline of physical function.

The normal sagittal spine has physiological curvatures: thoracic kyphosis (TK) and lumbar lordosis (LL). Spinal malalignment is associated with poor physical function, quality of life, increased risk of falls and musculoskeletal disorders such as osteoporosis and lumbar spondylolisthesis (Ishikawa et al, 2013; Katzman et al, 2015; Li, Chau, Dai, and Tiwari, 2021; Tokida et al, 2019). Naturally, positioning the spinal alignment in its physiological curvatures enhances spinal stability and minimizes muscle activity and energy expenditure required to maintain posture (Barrey, Roussouly, Perrin, and Le Huec, 2011; Roussouly and Nnadi, 2010). However, muscles attached to the spine and intervertebral discs degenerate with age (Tian et al, 2023), causing alignment changes, such as an increase in TK and loss of LL (Asai et al, 2017; Tokida et al, 2019). Thus, the relationship between TK in the sagittal plane and physical function and that between LL and physical function has been investigated in community-dwelling older adults. Miyazaki et al. (2013) cross-sectionally investigated factors related to gait function in healthy older men and showed that the combination of low knee extensor strength and LL loss explained gait dysfunction. In addition, Ishikawa et al. (2013) reported that loss of LL, that is, kyphosis deformity of the lumbar spine, is associated with postural instability and that older adults whose LL is 3° and less are at a higher risk of falling. However, there is no consensus regarding the relationship between TK and physical function (Koele et al, 2022; Lorbergs et al, 2017).

In previous studies (Ishikawa et al, 2013; Koele et al, 2022; Lorbergs et al, 2017; Miyazaki et al, 2013), LL and TK were evaluated separately as alignment indices of each segment of the spine, and their relationship with physical function was examined. However, because thoracic and lumbar curvature patterns vary among individuals (Wang et al, 2012), it is necessary to evaluate the overall alignment pattern of the spine when examining changes in spinal alignment related to poor physical function.

The difference between LL and TK (LL minus TK; LL-TK) is used to evaluate the overall thoracic and lumbar curvatures (Yang et al, 2016). In the kyphosis posture, LL usually decreases, and TK increases with aging, and then LL-TK becomes smaller. Decreased LL-TK has been reported to be correlated with age (Zhou et al, 2020) and is more correlated with sagittal vertical alignment (SVA), which indicates whole spine inclination, than with TK or LL (Yang et al, 2016). Therefore, since decreased LL-TK is considered a better indicator of age-related changes in the overall spinal alignment than TK or LL alone, LL-TK may be more associated with physical function. However, it is unclear whether LL-TK is associated with physical function in community-dwelling older adults, and whether it is more relevant than TK or LL alone.

The purpose of the current study was to identify whether LL-TK is related to physical function in community-dwelling older adults, and whether it has a stronger association than TK or LL alone. We hypothesized that decreased LL-TK would be associated with poor physical function and would be more associated with physical function than TK or LL alone.

MATERIALS AND METHODS

Study design and participants

This cross-sectional study analyzed the Nagahama Prospective Cohort for Comprehensive Human Bioscience (Nagahama Study) between 2013 and 2017, a population-based cohort (Taniguchi et al, 2021). We recruited participants aged 30-74 years at recruitment, who lived independently and without serious health problems through mass communication in the community, such as magazines and newspapers, and personal solicitation. In all, 9,850 participants were enrolled in the second survey. A flowchart of the participant selection process is shown in Figure 1. The inclusion criteria for this study were as follows: older adults aged 60 years or older, living independently in the community, and who had undergone optional physical assessments (n=2,121). Participants with missing data were also excluded (n=121). The exclusion criteria were as follows: (1) incomplete physical assessment as a result of physical dysfunction, including severe pain or fatigue while measuring physical function; and (2) central or peripheral neuropathy, history of back or lower limb joint surgery, acute back pain, rheumatoid arthritis, chronic kidney disease requiring dialysis, or chronic obstructive pulmonary disease. A total of 1,674 participants were included in the analysis.

[Figure 1 near here]

The study was conducted in accordance with the principles of the Declaration of Helsinki. The Ethics Committee of Kyoto University Graduate School of Medicine (No. G278) and the Nagahama Municipal Review Board approved the study protocol. All participants were informed about the study in advance, and written informed consent was obtained.

Sagittal spinal alignment

Sagittal spinal alignment parameters were measured using a Spinal Mouse (Index Ltd., Japan). The Spinal Mouse is a computer-assisted electronic device that noninvasively measures the spine angle by tracing the midline between the C7 and S3 vertebrae. A sum of the eleven segment angles from Th1/2 to Th11/12 indicated TK (positive values indicated kyphosis) while a sum of the six segment angles from Th12/L1 to L5/S1 indicated LL (positive values indicated lordosis). LL-TK was calculated from the LL and TK values measured, and lower LL-TK values indicate increased TK or decreased LL (Yang et al, 2016). The relevance of spinal alignment measured by the Spinal Mouse was validated by comparison with radiographic measurements, with TK and LL showing significantly strong correlations ($r = 0.804$ and $r = 0.863$, respectively) (Miyakoshi et al, 2004). We measured sagittal spinal alignment during static standing three times and used the average value for the analysis. The same examiner performed all TK and LL angle measurements using a spinal mouse, which demonstrated high intra-rater reliability (intraclass correlation coefficient; TK, 0.927; LL, 0.984).

Physical function

For physical function assessment, single-leg standing, five chair stands, and usual gait speed were selected for easy measurement in clinical practice. Single-leg standing was measured on the participant's dominant leg with the eyes open and without support (Goldberg, Casby, and Wasielewski, 2011), and assessed as representative of balance function. The measurement ended when the raised leg touched the floor or when the axial leg moved. The maximum duration was 60 s. Five-times chair-stand test was assessed as a representative overall lower limb strength (Porto et al, 2023). This test measured the time taken to stand up five times from a chair with a height of 40 cm without armrests, with arms crossed as quickly as possible (Bohannon, 2006).

Measurements were performed only once. As a representation of gait function, the usual gait speed (m/s) was measured by taking the time to pass between wireless phototubes (Brower Timing Systems Ltd., USA) placed 4 and 10 m from the starting line. Since knee extensor muscle strength is strongly related to sit-to-stand (Lord et al, 2002) and gait speed (Miyazaki et al, 2013), we measured the maximal isometric muscle strength of knee extension as an adjustment variable. A dynamometer (Musculater; OG Giken, Japan) was used for measurements, and the participants were seated with their hips and knees flexed at 90°. The dynamometer sensor was placed 25 cm distal to the knee joint and the values were converted to torque (Nm) by multiplying the measured values by the lever arm length (m). After the practice trials, knee extensor strength was measured twice in the right leg, and the higher value was used for analysis (Inoue et al, 2017).

Health conditions and comorbidities

The presence of chronic low back pain, knee pain, osteoporosis, and diabetes mellitus were confirmed by reviewing a self-reported questionnaire. Chronic low back pain was defined as continuous pain lasting over 3 months until present. Knee pain was defined as pain while walking or climbing stairs.

Statistical analysis

All data were expressed as mean $\pm$ standard deviation (SD) or frequency. The relationship between spinal alignment and physical function (single-leg standing, five-times chair-stand, and usual gait speed) were evaluated using Pearson's correlation coefficient. The correlation coefficient reference ranges were as follows; $0 < r < |0.2|$, no correlation; $|0.2| \leq r < |0.4|$, weak; $|0.4| \leq r < |0.6|$, moderate; $|0.6| \leq r < |0.8|$, strong; $|0.8| \leq r < 1$, extremely strong. To determine which spinal alignment indicators were related to physical function, stepwise multiple regression analyses were performed with each physical function measure as a dependent variable. Spinal alignment indices with significant correlations by Pearson's coefficient were used as independent variables with adjustments for age, sex, body mass index (BMI), and knee extensor strength. All statistical analyses were performed using the SPSS software (version 22.0, IBM Japan Inc., Japan). The level of significance was set at $p < 0.05$.

RESULTS

Table 1 presents the participants' characteristics. [Table 1 near here]

Table 2 presents the correlation between spinal alignment and physical function. Single-leg standing showed significant positive correlations with LL and LL-TK ($r = 0.161$, $p < 0.001$ and $r = 0.188$, $p < 0.001$, respectively), but was considered to indicate almost no correlation because of the small correlation coefficient. Five-chair standing exhibited significant weak negative correlations with LL and LL-TK ($r = -0.209$, $p < 0.001$; $r = -0.219$, $p < 0.001$, respectively). Furthermore, usual gait speed was significantly positively correlated with LL and LL-TK ($r = 0.191$, $p < 0.001$ and $r = 0.209$, $p < 0.001$, respectively), and these relationships ranged from almost no to weak correlation. There was no significant correlation between TK and all physical function measures.

[Table 2 near here]

Table 3 presents the results of multiple regression analyses with LL and LL-TK as independent variables. The results indicated that single-leg standing ($\beta = 0.092$, 95% confidence interval [CI] = 0.071 to 0.214, $p < 0.001$) and five-times chair-stand ($\beta = -0.142$, 95%CI = -0.037 to -0.019, $p < 0.001$) were significantly associated with LL-TK, but not LL. Usual gait speed was significantly correlated with both LL ($\beta = 0.087$, 95%CI = 0.001–0.003, $p = 0.003$) and LL-TK ($\beta = 0.121$, 95%CI = 0.001–0.004, $p < 0.001$).

[Table 3 near here]

DISCUSSION

This study found that low LL-TK may be associated with poor physical function independent of age, sex, BMI, and knee extensor strength in community-dwelling older adults. In particular, for balance function and sit-to-stand ability, the association may be stronger than that with TK or LL alone. These findings support our hypothesis and suggest that LL-TK is a valuable spinal alignment index related to physical function in community-dwelling older adults. This is the first study to demonstrate the relationship between decreased LL-TK and physical dysfunction in community-dwelling older adults.

The results of multiple regression analyses showed that LL-TK was significantly associated with single-leg standing, five-time chair standing, and usual gait speed. In response to kyphotic changes with decreased LL-TK, compensatory mechanisms such as pelvic retroversion and knee flexion are recruited to restore sagittal equilibrium and to maintain an upright posture and horizontal gaze (Barrey, Roussouly, Perrin, and Le Huec, 2011; Roussouly and Nnadi, 2010). It has been suggested that, in patients with increased pelvic retroversion and knee flexion compensatory against spinal malalignment, the lower limb muscle activity required to maintain a standing posture are significantly increased (Yamato et al, 2023). Such increased muscle activity may contribute to increased energy expenditure and rapid muscle fatigue (Abitbol, 1995), affecting chair standing and gait, and requiring lower-extremity muscle exertion. In addition, when the compensatory mechanism becomes insufficient owing to the

progression of spinal deformity or long-term overloading of muscles and joints, the entire spine tilts forward, and the SVA increases (Barrey, Roussouly, Perrin, and Le Huec, 2011). Decreased LL-TK has been reported to be correlated with larger SVA (Yang et al, 2016) and increased forward spinal tilt causes anterior displacement of the axis of gravity, poor postural stability, impaired balance, etc (Ishikawa et al, 2013). SVA has been shown to be associated with single-leg standing time, chair standing test, and 6 m walk time (Hira et al, 2021). Furthermore, the relationship between the SVA and physical function was observed even after adjusting for age and sex (Tokida et al, 2019). Considering these reports, the decrease in LL-TK, or the kyphotic change of the spine, causes increased muscle activity due to alignment changes in the pelvis and knee joints and poor balance due to spinal tilt, which may be associated with physical functional decline.

The current study indicated that both LL-TK and LL were significantly correlated with the usual gait speed. LL has been associated with maximum gait speed in healthy older men independent of age and knee extensor strength (Miyazaki et al, 2013), which is partially consistent with our results. However, the correlation coefficient between the usual gait speed and LL was low ($r = 0.191$, $p < 0.001$), suggesting almost no correlation. Notably, the correlation coefficient between physical function and LL-TK score was low. Increased SVA and decreased LL-TK, was associated with reduced hip extension angle during the stance phase, leading to decreased step length and gait speed (Kawkabani et al, 2021). Particularly, because

lower-limb function is related to the usual gait speed, the relationship between the usual gait speed and spinal malalignment may be weak. In contrast, TK was not significantly correlated with any physical function. The prevalence of thoracic hyperkyphosis (Li, Chau, Dai, and Tiwari, 2021) increases with age. The participants in this study (mean age; 67.4 years) were relatively younger than those in previous studies (mean age; 72.9–80.5 years) (Katzman et al, 2015; Koele et al, 2022) and had fewer kyphosis deformities. In fact, the average TK in this study was 36°, whereas that in the previous study (Li, Chau, Dai, and Tiwari, 2021) was 49°. Therefore, increased TK alone may have less of an effect on physical function.

A previous study that examined whether LL-TK can predict clinical outcomes in patients with adult degenerative scoliosis showed that decreased LL-TK was more closely associated with postoperative disease-specific patient-reported outcome measures than other spinopelvic parameters (Zhou et al, 2019). In previous studies (Yang et al, 2016; Zhou et al, 2019), LL-TK was reported to reflect a local compensatory mechanism in the spine, that is, TK decreases to rebalance the forward moving center of gravity due to the loss of LL. However, compensatory alignment changes are limited because older adults have less spinal flexibility (Saidu et al, 2011). Thus, a decrease in LL or an increase in TK could lead to decreased LL-TK. Liu et al. (2023) compared the spinopelvic parameters among four groups of healthy adults according to the Roussouly classification of postural patterns (Roussouly, Gollogly, Berthonnaud, and Dimnet, 2005). Their results showed a significant difference in LL-

TK, with a decreasing trend as kyphosis increased, indicating the diagnostic value of LL-TK for posture types. These previous studies evaluated the LL-TK using standing spine lateral radiograph. The results of this study, which revealed associations between physical function and LL-TK measured non-invasively using a Spinal Mouse, were consistent with previous findings. These findings are clinically significant, suggesting that the assessment of LL-TK, which evaluates the overall thoracolumbar curvature, is useful as a spinal alignment index related to physical function in older adults.

This study has several limitations. First, SVA, which is associated with LL-TK and physical function, was not assessed. SVA is measured by the horizontal distance between C7 and the sacral endplate, it is affected by the alignment of the pelvis and lower extremities, while LL-TK is an index that evaluates only spinal deformity. A previous study (Zhou et al, 2019) reported that decreased LL-TK was more associated with postoperative functional scores than SVA. Second, the cervical spine alignment was not investigated in this study, and the relationship between cervical spine malalignment and physical function remains unclear. Previously, cervical spine alignment showed a relatively small effect on physical function in the lower limbs and is important to evaluate LL-TK (Tokida et al, 2019). Third, this study included individuals with various physical activity levels, including those with chronic musculoskeletal disorders who experienced no serious pain during physical assessments. However, whether these results can be generalized to older adults or used for disease-specific assessments is unclear. Finally, because this was a cross-sectional

study, we could not identify the causal relationships between spinal alignment and physical function. However, the results of the present study clearly indicate that LL-TK is associated with physical function, independent of age and other covariates, which supports the necessity of considering not only TK or LL alone but also LL-TK when evaluating spinal alignment among older adults.

CONCLUSIONS

This study showed that decreased LL-TK, which evaluates the overall thoracolumbar curvature, may be associated with poor physical function, and that the association may be stronger than that with TK or LL alone. This suggests that the LL-TK is a valuable spinal alignment index related to physical function in older adults. The findings of this study are important for better understanding the relationship between spinal alignment and physical function in older adults.

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DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Characteristics of the participants

Parameter	Mean	SD	Range [min, max]
Age(years)	67.4	5.3	[60, 80]
Sex; female (n, %)	1099 (65.7%)		
BMI(kg/m ²)	22.3	3.0	[14.7, 34.6]
Chronic low back pain (n, %)	881 (52.6%)		
Knee pain (n, %)	744 (44.4%)		
Osteoporosis (n, %)	236 (14.1%)		
Diabetes mellitus (n, %)	178 (10.6%)		
Knee extensor strength(Nm)	117.0	50.3	[21.1, 372.4]
TK(°)	36.1	11.1	[-9.0, 79.0]
LL(°)	13.5	12.2	[-45.0, 53.0]
LL-TK(°)	-22.6	12.6	[-73.0, 25.0]
Single-leg standing(s)	45.0	19.6	[1.0, 60]
Five-times chair-stand(s)	8.6	2.5	[3.9, 27.3]
Usual gait speed(m/s)	1.3	0.3	[0.6, 2.2]

Abbreviation: BMI, body mass index; TK, thoracic kyphosis; LL, lumbar lordosis; LL - TK, lumbar lordosis minus thoracic kyphosis

Table 2. Correlations between spinal alignment and physical function

	Single-leg standing	Five-times chair-stand	Usual gait speed
TK	$r = -0.035, p = 0.151$	$r = 0.019, p = 0.434$	$r = -0.027, p = 0.264$
LL	$r = 0.161, p < 0.001$	$r = -0.209, p < 0.001$	$r = 0.191, p < 0.001$
LL-TK	$r = 0.188, p < 0.001$	$r = -0.219, p < 0.001$	$r = 0.209, p < 0.001$

Abbreviation: BMI, body mass index; TK, thoracic kyphosis; LL, lumbar lordosis; LL - TK, lumbar lordosis minus thoracic kyphosis

Table 3. Results of multiple regression analysis

Dependent variable	Independent variable	B	95% CI	β	p value
Single-leg standing					
	LL-TK	0.143	0.071, 0.214	0.092	<0.001
Five-times chair-stand					
	LL-TK	-0.028	-0.037, -0.019	-0.142	<0.001
Usual gait speed					
	LL-TK	0.003	0.001, 0.004	0.121	<0.001
	LL	0.002	0.001, 0.003	0.087	0.003

Adjusting for age, sex, BMI, and knee extensor strength.

Abbreviation: B, partial regression coefficient; 95% CI, 95% confidence interval; β , standardized regression coefficients; LL, lumbar lordosis; LL-TK, lumbar lordosis minus thoracic kyphosis

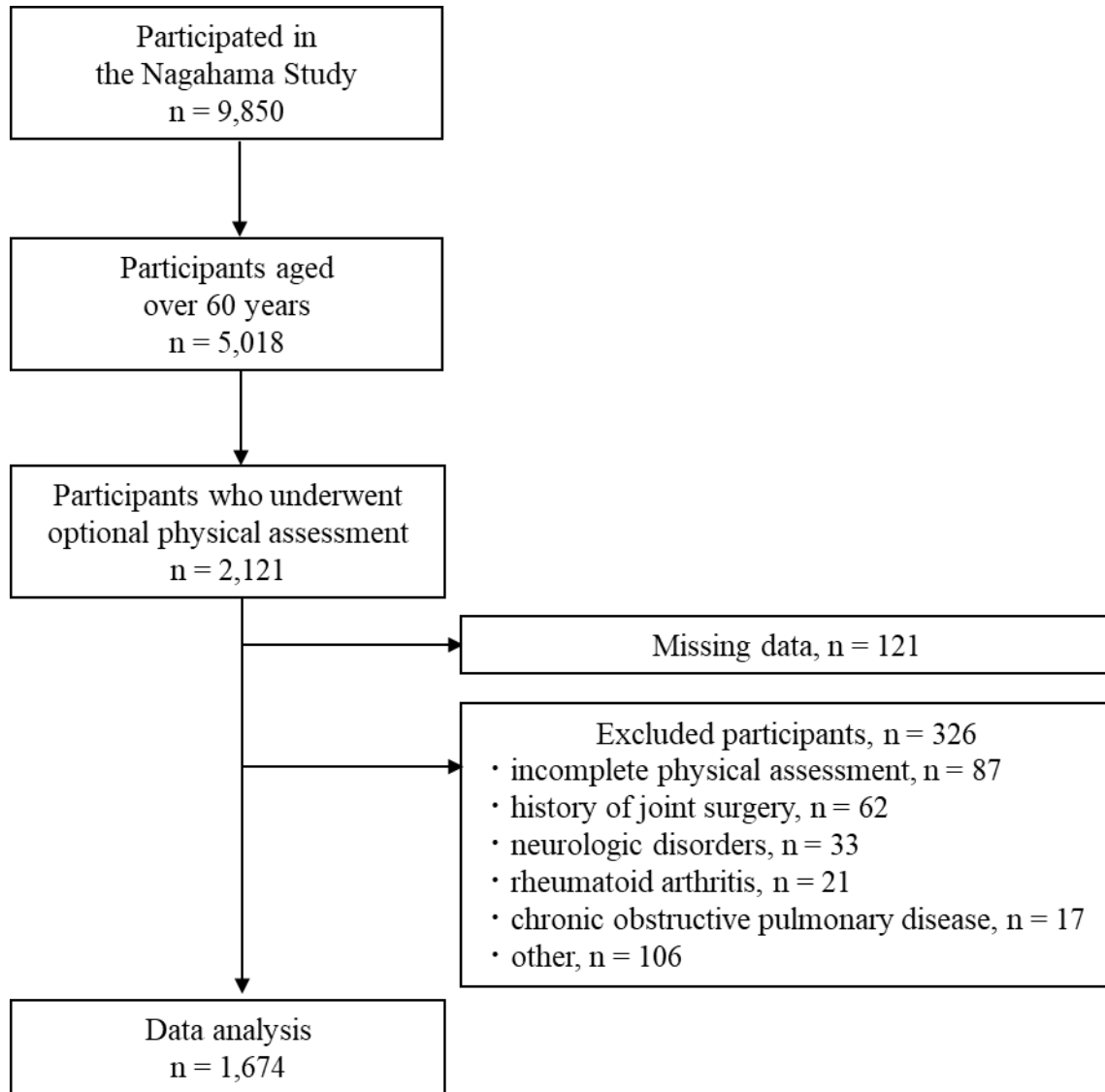


Figure 1. Flowchart for participants selection from the Nagahama Study