Computed Tomographic Assessment of Age- and Gender-Specific Sagittal Lumbopelvic Alignment in a Japanese Population

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Abstract:

Introduction: Previous studies have reported differences in lumbopelvic alignment between standing and supine positions. Computed tomography (CT) images taken in the supine position are often used for clinical studies in addition to standing radiographs, although not frequently. Our study aims to clarify normative values of CT-evaluated lumbopelvic parameters and the characteristics of age- and gender-related lumbopelvic alignment in the supine position.

Methods: Patients undergoing CT scans of abdominal or lumbar regions for reasons other than low back disorders were included (n=581). Sagittal multiplanar reconstruction CT images were obtained, and lumbar lordosis (LL), L5-S1 angle, and sacral slope (SS) were measured. Mean values of the parameters in patients aged 59 years and under, 60-69, 70-79, and 80 and over, and in males and females, were calculated. Age- and gender-related differences in these parameters were statistically analyzed.

Results: Among the four age groups, patients 80 years and over showed significantly lower LL and SS than patients aged 70-79. Females 80 years and over showed significantly lower LL and SS than all other age groups, but those in males did not. The comparison between males and females showed no significant differences in LL and SS; however, the L5-S1 angle was significantly higher in males than in females. In patients 80 years and over, females showed significantly lower LL and SS than in males.

Conclusions: This study provides normative CT-evaluated lumbopelvic parameters, such as LL, L5-S1 angle, and SS, which will be utilized for comparisons in future studies. The present study first revealed that pelvic retroversion and lumbar kyphosis occur in elderly females in the supine position, which raised a possibility that age-related decrease of LL and SS in females occurs at an older age in the supine position than in the standing position.

Keywords:

Lumbopelvic, alignment, lumbar lordosis, sacral slope, computed tomography (CT), supine, age, general population

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Introduction

The importance of sagittal lumbopelvic alignment when treating patients with spinal disorders has been widely recognized[1,2)]. Lumbopelvic alignment is usually evaluated with radiographs taken in the standing position. Several studies have recently used computed tomography (CT) in evaluating lumbopelvic parameters[3-5)]. When evaluated using radiographs, lumbopelvic parameters are affected by the direction and distance between the patient and the radiographic sys-

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tem. After imaging, CT images can be reconstructed to sagittal and coronal planes, and the adjusted planes can be used for evaluation. Therefore, CT has an advantage in accuracy of quantitative measurement of lumbopelvic parameters. However, CT is taken in the supine position, while lumbopelvic parameters are usually measured in the standing position. CT-evaluated lumbopelvic alignment has usability in a clinical setting, as well as lumbopelvic alignment evaluated using standing lateral radiographs, although they have different meanings. In the supine position, lumbopelvic alignment is mainly determined by structural factor of lumbar spine and thus should be constant. In the standing position, lumbopelvic alignment should be more influenced by functional factors, such as muscle strength, pain, and neurological conditions. Therefore, lumbopelvic alignment in the standing position is thought to be easily changed depending on the patient's conditions. Moreover, when treating patients with severe pain, spinal trauma, or extremely limited physical activities, standing radiographs are not often taken. In such cases, lumbopelvic parameters evaluated in supine radiographs, CT, or magnetic resonance imaging (MRI) would be utilized in evaluating patient pathology. Park et al. reported a slight difference in the parameters depending on posture and concluded that the majority of patients demonstrated decreased lumbar lordosis (LL) and increased sacral slope (SS) between standing and supine positions[4]. Chevillotte et al. examined lumbopelvic parameters in standing and supine positions and reported the same results as Park et al.[6] They proposed a possible explanation that a slight hyperextension of the hip in the supine position may increase SS. They also showed that correlations between LL and pelvic parameters were strongest in the supine position, concluding that spinal curves assessed in the supine position can be utilized in a clinical setting, especially when patients cannot maintain a standing position[6].

It is generally recognized that lumbopelvic parameters vary depending on age and gender[7-12]. However, there has been no study clarifying detailed age- and gender-specific values of CT-evaluated lumbopelvic parameters. Therefore, this study was designed to understand how spinopelvic alignment in the supine position changes age dependently in each gender. Moreover, we propose that baseline data is required for future reference; thus, this study was conducted to clarify age- and gender-specific CT-evaluated lumbopelvic parameters in patients undergoing CT scans for reasons other than low back disorders.

Materials and Methods

Consecutive 708 patients undergoing CT scans of abdominal or lumbar regions between July 2015 and February 2016 in our institution were included. Only patients undergoing CT scan for reasons other than low back disorders were included. Patients who had prevalent vertebral fracture between T10 and L5 levels and who had received lumbar spinal fusion surgery were excluded. Finally, 581 of 708 patients were included in the present study.

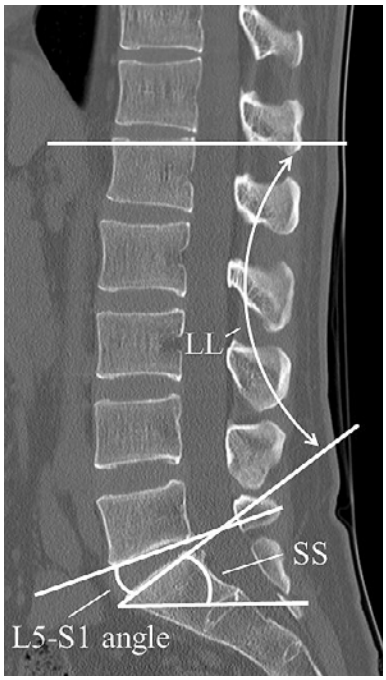

Figure 1. Measurement of lumbar lordosis (LL), L5–S1 angle, and sacral slope (SS) on a midsagittal view of reconstructed computed tomogram.

Patients' age and gender were reviewed, and sagittal multiplanar reconstruction CT images were obtained and evaluated. LL (angle between superior endplates of L1 and S1), L 5-S1 angle (angle between inferior endplate of L5 and superior endplate of S1), and sacral slope (SS, angle between superior endplate of S1 and horizontal plane) were measured using the midsagittal view (Fig. 1).

We first calculated the mean values (±SD) of LL, L5-S1 angle, and SS and then calculated the values in males and females, respectively. We then calculated the mean values (±SD) of LL, L5-S1 angle, and SS in four age groups: 59 and under, 60-69, 70-79, and 80 and over. Age- and gender-related differences in these parameters were then investigated.

The study was carried out in accordance with the Declaration of Helsinki, and the study protocol was approved by the Institutional Review Board of our Medical Center (ECMC No. 30). Informed consent was obtained from all patients.

Data analysis

An unpaired t-test was used to compare values between males and females, and one-way analysis of variance test or the Kruskal-Wallis test was used to compare values among the four age groups. In the case of a significant one-way ANOVA result, a post hoc test (Tukey's test) was performed if the data had equal variances. If not, Dunn's multiple comparison test was used for comparison. Statistical analyses were carried out using StatMate IV software (ATMS, Tokyo,

Japan). A p value <0.05 was considered statistically significant.

Results

The study sample included 581 patients (mean age: 61.8± 19.1 years old; 361 males/220 females, Table 1). Patients were distributed according to age as follows: 59 years and under, n=218 (137 males; 81 females); 60-69 years (60s), n =133 (83 males; 50 females); 70-79 years (70s), n=124 (79 males; 45 females); and 80 years and over, n=106 (62 males; 44 females).

Table 1. Mean Values of Age, Lumbar Lordosis (LL), L5–S1 Angle, and Sacral Slope (SS) in Males and Females.

	Males (n=361)	Females (n=220)	p
Age (years)	62.0±18.2 (9-92)	61.4±20.4 (14-95)	NS
LL (°)	38.7±10.0	38.2±11.2	NS
L5–S1 angle (°)	12.4±4.9	10.8±5.5	*0.00045
SS (°)	36.6±7.7	35.7±8.2	NS

Data are presented as the mean±standard deviation.
Asterisks indicate statistically significant differences (p<0.05).
NS: not significant

Differences of LL, L5-S1 angle, and SS among the age groups

Analysis among the four age groups of the total 581 patients showed significant differences in LL between those 59 years old and under and those in their 70s and between those in their 70s and 80 years old and over (Fig. 2). No significant difference in L5-S1 angle was found among the four age groups (Fig. 3). No significant difference in SS was found among those 59 years old and under and those in their 60s and 70s; however, patients aged 80 years and over showed significantly lower SS than those in their 70s (Fig. 4).

Analysis among the four age groups was performed in

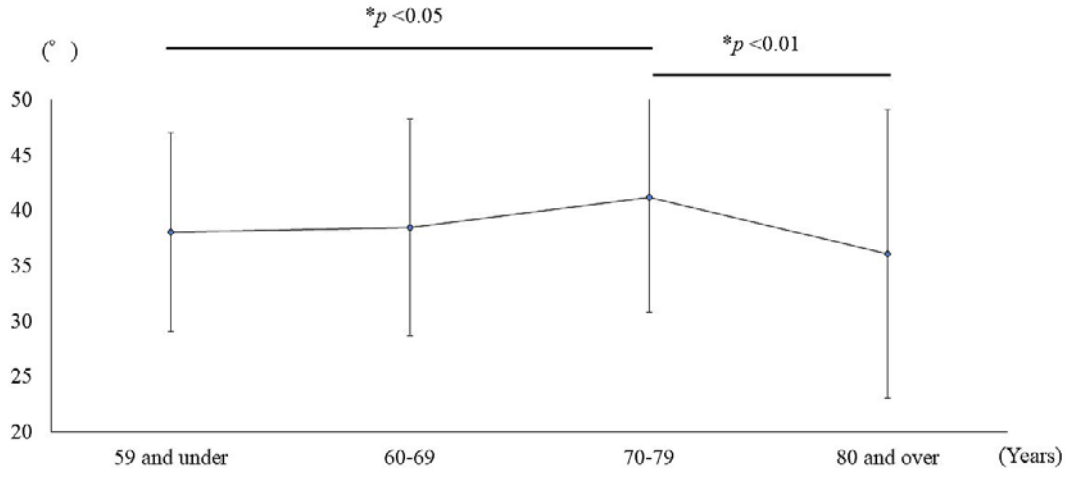

Figure 2. Mean values of age-specific lumbar lordosis (°) measured using reconstructed computed tomography (CT) sagittal images. Error bars represent standard deviation. Asterisks indicate statistically significant differences (*p<0.05; **p<0.01).

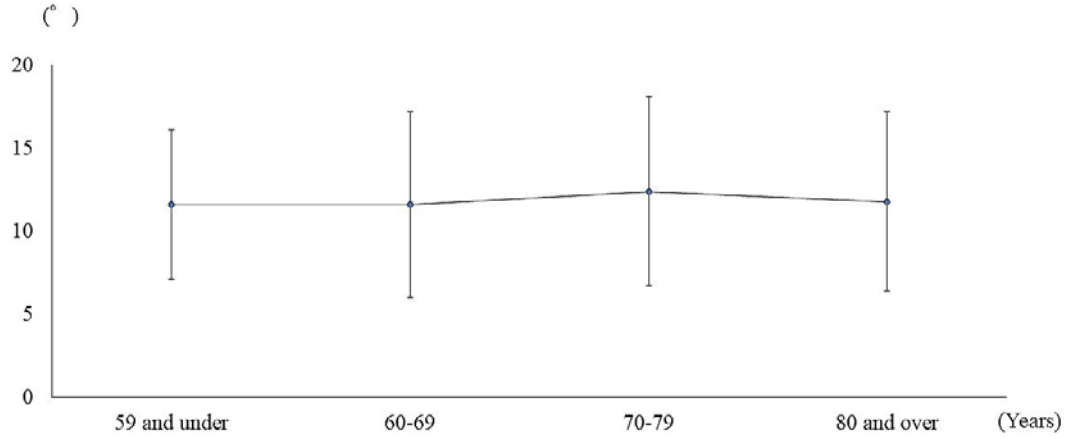

Figure 3. Mean values of age-specific L5–S1 angle (°) measured using reconstructed computed tomography (CT) sagittal images. Error bars represent standard deviation. No significant difference was observed among the four age groups.

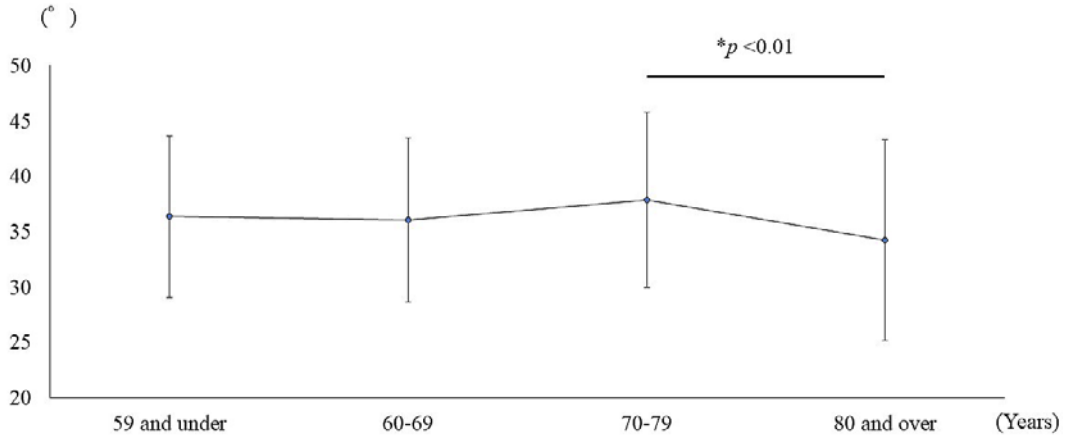

Figure 4. Mean values of age-specific sacral slope (°) measured using reconstructed computed tomography (CT) sagittal images. Error bars represent standard deviation. Asterisk indicates statistically significant difference (*p<0.01).

Table 2. Age (in Years) - and Gender-Specific Lumbar Lordosis (LL), L5–S1 Angle, and Sacral Slope (SS).

Age		59 and under	60s	70s	80 and over	p	*Post hoc (Tukey test)*
LL (°)	Males	37.8±8.5	38.1±9.8	41.1±10.2	38.6±12.1	NS	
	Females	38.3±9.8	39.1±9.6	41.3±10.9	32.7±13.5	*0.0019 (ANOVA)	*59 vs. 80, *60 vs. 80, *70 vs. 80
	p (males vs. females)	NS	NS	NS	*0.026		
L5–S1 angle (°)	Males	12.1±4.5	12.0±5.2	13.3±5.2	12.6±5.0	NS	
	Females	10.7±4.5	11.0±6.0	11.0±6.3	10.7±5.8	NS	
	p (males vs. females)	*0.024	NS	*0.042	NS		
SS (°)	Males	36.5±7.0	35.9±7.4	38.0±7.7	36.1±9.0	NS	
	Females	36.3±7.7	36.3±7.3	37.7±8.2	31.7±7.6	*0.0027 (ANOVA)	*59 vs 80, *60 vs 80, *70 vs 80
	p (males vs. females)	NS	NS	NS	*0.014		

Data are presented as the mean±standard deviation.
Asterisks indicate statistically significant differences (p<0.05).
NS: not significant

males (n=361) and in females (n=220) (Table 2). In males, no significant differences in LL, L5-S1 angle, and SS were observed among the four age groups. In females, patients aged 80 years and over showed significantly lower LL and SS than all other age groups (Table 2). In males, although patients aged 80 years and over showed lower LL and SS, statistical significance was not achieved.

Differences of LL, L5-S1 angle, and SS between males and females

The comparison of the parameters between males and females in the total 581 patients showed no significant differences, except the L5-S1 angle showing a significantly higher value in males (12.4±4.9°) than in females (10.8±5.5°, Table 1).

Within each age group, the parameters were compared between males and females; the results are shown in Table 2. In patients 80 years and over, females showed significantly lower LL and SS than males; no significant differences in these parameters were observed between males and females in the other age groups (59 years and under, 60s, and 70s) (Table 2). Males showed higher L5-S1 angle than females in all age groups; however, significant differences were found only in age groups 59 years and under and 70s (Table 2).

Discussion

This is the first study showing age- and gender-specific values of LL, L5-S1 angle, and SS evaluated by CT images taken in the supine position. Our study population was limited to patients who underwent CT for reasons other than low back disorders; thus, the data of this study would seem to closely resemble those of a Japanese general population. Several studies exist describing lumbopelvic parameters evaluated by standing radiograph in asymptomatic volunteers thought to be similar to a general population[7-12]. According to previous reports, LL and SS differ depending on age and gender[10,13,14]. It is recognized that both LL and SS decrease as patients age[10]. Generally, age-dependent decreases of LL and SS are more noticeable in females than in

males and occur from a younger age in females[9,10,14]. Therefore, in elderly patients, particularly in females, pelvic retroversion and lumbar kyphosis occur as patients get older. Previous studies reported that both male and females aged 80 years and over showed lower LL and SS in standing position than other age groups[9,10,14]. The results of our study are consistent with the previous studies regarding the age-dependent changes in females. However, our study did not show a significant decrease in LL and SS in males aged over 80 years. An explanation for the difference in the results is that our study examined lumbopelvic alignment in the supine position, while previous studies examined those in the standing position. As already mentioned, the meanings of lumbopelvic alignment in a standing position and in a supine position are different. Our results first demonstrated that pelvic retroversion and lumbar kyphosis in elderly females could be observed in the supine position as well as in the standing position; however, in elderly males, such age-related changes were not observed in the supine position. From these observations, age-related pelvic retroversion and lumbar kyphosis in females are suggested to occur both functionally and structurally; however, those changes are mainly caused by functional factors in males aged 80 years and over.

In terms of age-specific values of LL and SS, our results using CT showed a tendency that LL is slightly lower and SS is slightly higher than data obtained using standing radiographs[10]. This tendency is also consistent with previous reports[6]. Therefore, we believe our age- and gender-specific data evaluated using CT data are reliable and can be utilized as baseline data for future reference. However, a different result was found between previous studies and ours[10,14]. In the previous studies, females aged 70-79 showed significantly lower LL and SS than males[10,14], while our study showed no significant difference. One explanation for this difference is that lumbar kyphosis and pelvic retroversion occur in the standing position but not in the supine position in females aged 70-79, suggesting that such age- and gender-related changes first occur functionally (in standing) and then structural changes follow (in supine). From these observations, we should understand that there are differences in lumbopelvic parameters between the two positions and carefully utilize our data as baseline data for future reference.

There are a few studies examining the L5-S1 angle. Yukawa et al. reported that the L5-S1 angle shows a similar value between standing and supine position[13]. In their study, an age-dependent decrease of the L5-S1 angle was not observed until the eighth age decade. In this study, the angle of the L5-S1 disc was evaluated because we hypothesized that age-related changes of LL and SS are related to L5-S1 disc degeneration. However, there was no significant change in L5-S1 angle among the four age groups, until the ninth age decade. Although we found a significant difference in L 5-S1 angle between males and females, the difference was found in only two of the four age groups (59 and under and 70s), not in the age group 80 years and over when decreases of LL and SS occur. In this study, we found that males showed a higher L5-S1 angle than females; however, we could not find clinical significance of L5-S1 angle related to age-dependent changes of LL and SS.

There are several limitations of the present study. First, we have not directly compared LL and SS between the supine position and the standing position, because we retrospectively reviewed the CT data from patients who visited our hospital for reasons other than low back disorders. Fortunately, there are previous studies describing normative values of lumbopelvic parameters in the standing position in a Japanese general population[10,13,14]. By comparing our data with the previous studies, we found useful information that age-related changes of lumbopelvic alignment in the supine position occur at an older age than that in the standing position. Second, because of the study design using abdominal or lumbar CT without data from hip joints, we could not measure pelvic incidence, which is the key factor when discussing lumbopelvic alignment. Our study aims to clarify age-related changes of lumbopelvic parameters, such as LL, L5-S1 angle, and SS. Future study is needed to clarify age-specific changes of pelvic incidence.

Although our study has such limitations, our study also has a strong point. The patients included in this study visited our hospital and underwent CT for reasons other than lumbar spinal disorders. In addition, patients who had a prevalent thoracolumbar vertebral fracture were excluded. Because patients with diseases which significantly influence lumbopelvic alignment were strictly excluded, this study provides reliable data regarding age- and gender-related changes of lumbopelvic alignment in the supine position in a Japanese general population.

As already mentioned, it has been reported that LL decreases and SS increases in the supine position when compared with the standing position[4,6]. However, recent studies demonstrated that adult spinal deformity patients showed increased LL and SS in the supine position when compared with the standing position[15,16]. The difference in changes of LL and SS between healthy volunteers and adult spinal deformity patients provides an insight into the pathology of adult spinal deformity. We speculate that patients with spinal deformity may have functional disorders by which they are unable to maintain lumbar lordosis and pelvic anteversion in the standing position. In the supine position, the influence of functional factors may be minimized; thus, patients with spinal deformity show greater lumbar lordosis and pelvic anteversion in the supine position compared with the standing position. Unfortunately, we have not investigated these differences between the standing position and the supine position. However, the reference data of lumbopelvic parameters in standing and supine positions, provided by our study and the previous studies[10,13,14], can be utilized for future studies. In a clinical setting, lumbopelvic alignment evaluated in a supine position can be utilized, even in patients who are unable to maintain a standing position. Considering radiation

exposure, lateral radiographs or MRI taken in the supine position are also useful to evaluate lumbopelvic alignment in the supine position, although the accuracy of measurement may be inferior to CT evaluation. Reconstructed CT images of the lumbar spine provide several benefits, such as more accurate measurement[3,5] and more detailed evaluation of bone morphology[17,18].

In conclusion, our data will be useful and provide normative values of lumbopelvic parameters in the supine position, for comparison in future clinical research. The present study first revealed age-related changes of lumbopelvic parameters in the supine position in males and females, suggesting a possibility that age-related decreases of LL and SS in females occur at an older age in the supine position than in the standing position.

Disclaimer: Sumihisa Orita is one of the Editors of Spine Surgery and Related Research and on the journal's Editorial Committee. He was not involved in the editorial evaluation or decision to accept this article for publication at all.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Author Contributions: Yasuchika Aoki: conceptualization, formal analysis, writing of the original draft. Masahiro Inoue: formal analysis. Hiroshi Takahashi, Go Kubota, and Junya Saito: data curation and investigation. Atsuya Watanabe: conceptualization. Takayuki Nakajima and Yusuke Sato: validation and formal analysis. Arata Nakajima: writing, review, and editing. Yawara Eguchi and Sumihisa Orita: methodology and validation. Hiroyuki Fukuchi: methodology and investigation. Takayuki Sakai: methodology and resources. Shigehiro Ochi: project administration. Noriyuki Yanagawa: methodology and supervision. Koichi Nakagawa: conceptualization and project administration. Seiji Ohtori: supervision.

Ethical Approval: Eastern Chiba Medical Center No. 30.

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