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[Original article]

Reference values of lumbar spine range of motion by sex and age based on the assessment of supine trunk lateral bending-A preliminary study

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Abstract

[Purpose] The purpose of this study was to clarify the preliminary reference values for the lumbar spine range of motion associated with lateral bending exercises by gender and age group. [Methods] Subjects were 82 volunteers without low back pain, including five males and five females in each age group from 16-19 to 80-89 years. All subjects underwent radiographs of the lumbar spine with lateral flexion ; the range of lateral flexion of the vertebrae from T12 to the sacrum (ROLB) was measured twice by three observers. [Results] The ROLB of the entire T12-S1 of all subjects showed a significant negative correlation with age in both sexes ($p < 0.01$). The ROLB of the lumbar spine tended to be greater in females, with a statistically significant difference between those aged 16-19 and 70-79 ($p < 0.05$). Lateral flexion angles for each intervertebral segment were largest at L3-L4 and smallest at L5-S1 (0.7°). [Conclusion] Lumbar ROLB reference values were examined by gender and age group ; ROLB was greatest in L3-L4, and ROLB tended to be lower in older age groups.

Key words : Lumbar spine, range of motion, lumbar disc herniation, lateral bending exercise, radiography

Introduction

Low back pain interferes with daily life and has a significant impact on quality of life. According to the survey of living conditions by the Ministry of Health, Labor and Welfare in 2019[1], the prevalence rate of low back pain is 27-33% in Japan. One of the diseases that causes low back pain is lumbar disc herniation, which accounts for about 2% of all low back pain surgeries[2]. The prevalence of lumbar disc herniation in the US population is about 1% with a male-to-female ratio of 3.3 : 1.0, and it is estimated that 65% of the cases occur in people in their 20s and 30s[3]. In addition, in men, the risk of developing lumbar disc herniation is three times higher in heavy laborers than in clerical workers ; however, in women, it is the amount of work, not the type of work, that is more strongly associated with lumbar disc herniation risk[4].

For lumbar disc herniation, surgical procedures such as percutaneous endoscopic lumbar discectomy, microendoscopic discectomy, and the Love method have been reported with good results[5,6]. However, while there have been reports on conservative treatment for lumbar disc herniation, there are few reports on manual therapy[7].

We have used lateral bending exercise therapy as one of the manual therapies for lumbar disc herniation. In this method, the patient is placed supine, and the therapist manually rotates the pelvis to maintain lateral bending of the lumbar spine. Clinically, there are many cases in which pain reduction is observed after lateral bending exercise therapy, but the mechanism of this treatment is still un-

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clear. It is also unclear to what extent lateral bending mobility of the intervertebral spine can be achieved by lateral bending exercise therapy.

Lateral bending exercise therapy for lumbar disc herniation is performed to open the intervertebral space of the ipsilateral side and decrease the compression of the nerve root. However, since it has been performed manually without X-ray imaging, it is not clear which level is effective in this therapy.

Past reports on the range of motion of the spine include reports on the accuracy of measurement devices[8], range of motion in daily activities[9], postoperative assessment of range of motion[10], and range of motion in healthy subjects[11-13,15]. There have also been several studies[11,14-16] evaluating the range of motion of the lumbar spine in the supine position, Ochia *et al.*[14] reported axial rotation (range, 0.6° to 2.2°), lateral flexion (range, −3.6° to 3.0°), and forward translation (−1.2 mm to 5.4 mm) during torso rotation. Cook *et al*[16]. reported lateral flexion of 42 human cadaveric lumbar segments as L1-L2 (8.2° in women and 6.3° in men), L2-L3 (10.6° in women and 8.3° in men), L3-L4 (11.0° in women and 9.2° in men), L4-L5 (11.1° in women and 7.3° in men) and L5-S1 (9.0° in women and 6.4° in men). This study evaluated the range of lateral bending (ROLB) by gender and by intervertebral level, but not by age group. In other words, it is unclear to what extent the intervertebral range of motion by supine lateral bending exercise varies with age. Therefore, it is essential to provide reference values of ROLB to predict which level of disc herniation is more responsive to lateral bending exercise therapy in each gender and age group.

Since there are no previous reports to show the ROLB in each gender and age group, this study aimed to clarify the preliminary reference values of the intervertebral range of motion during lateral bending of the lumbar spine in healthy subjects by gender and age group. In addition, to clarify the responsive group to lateral bending exercise therapy, the characteristics of ROLB were evaluated by gender and age.

Subjects and methods

The study design was an observational study. This study was approved by the Ethics Committee of Fukushima Medical University (Reference number : General 2019-267).

Subjects

The subjects were healthy volunteers between the ages of 16 and 89 years old without low back pain. We targeted 80 subjects with five males and five females in each age group from 10-19 to 80-89 for recruitment. 82 applicants were received and all cases were enrolled in the study. The subjects were recruited through the posting of a recruitment notice describing the study at Fukushima Medical University Hospital. More than half of the participants were university employees, and the rest were referred by patients' family members or high school students in the neighborhood, who were selected as participants without back pain. The prevalence of chronic diseases and body mass index were not determined. After explaining the purpose and methods of the study in writing, those who agreed to participate were enrolled. To establish a preliminary reference value, we set the number of participants at 10 in each age group, for a total of 80, in consideration of the actual number of people who could be recruited. The exclusion criteria were low back pain at the time of the study and a history of lumbar spine surgery.

Methods

Plain radiographs were taken during lumbar spine lateral bending in the left and right directions. A radiographer at our hospital, who was not involved in the study, took the radiographs. For all study subjects, an experienced judo therapist was in charge of the lumbar lateral bending exercise.

Anteroposterior radiographs from T12 to the sacrum were taken during left and right lateral bending. The subject was placed in the supine position with bilateral hip and knee joints flexed 90 degrees, and the practitioner of the lateral bending exercise grasped the pelvis with both hands and flexed the lumbar region laterally to the maximum (Figure 1A, B). Radiographs were taken while the subject maintained this position. All subjects were first photographed in the right lateral bending position, followed by light exercise in the standing position for about 5 minutes, and then were photographed in the left lateral bending position. The captured image data were recorded on a CD-ROM and used for the measurements.

Image analysis

The images were measured by three observers who were not involved in the data collection. DICOM Viewer Sycorax (Codedynamix Co., Ltd. Yoko-

Fig. 1. Manual Lateral Bending (A). Overhand view during lateral bending (B).

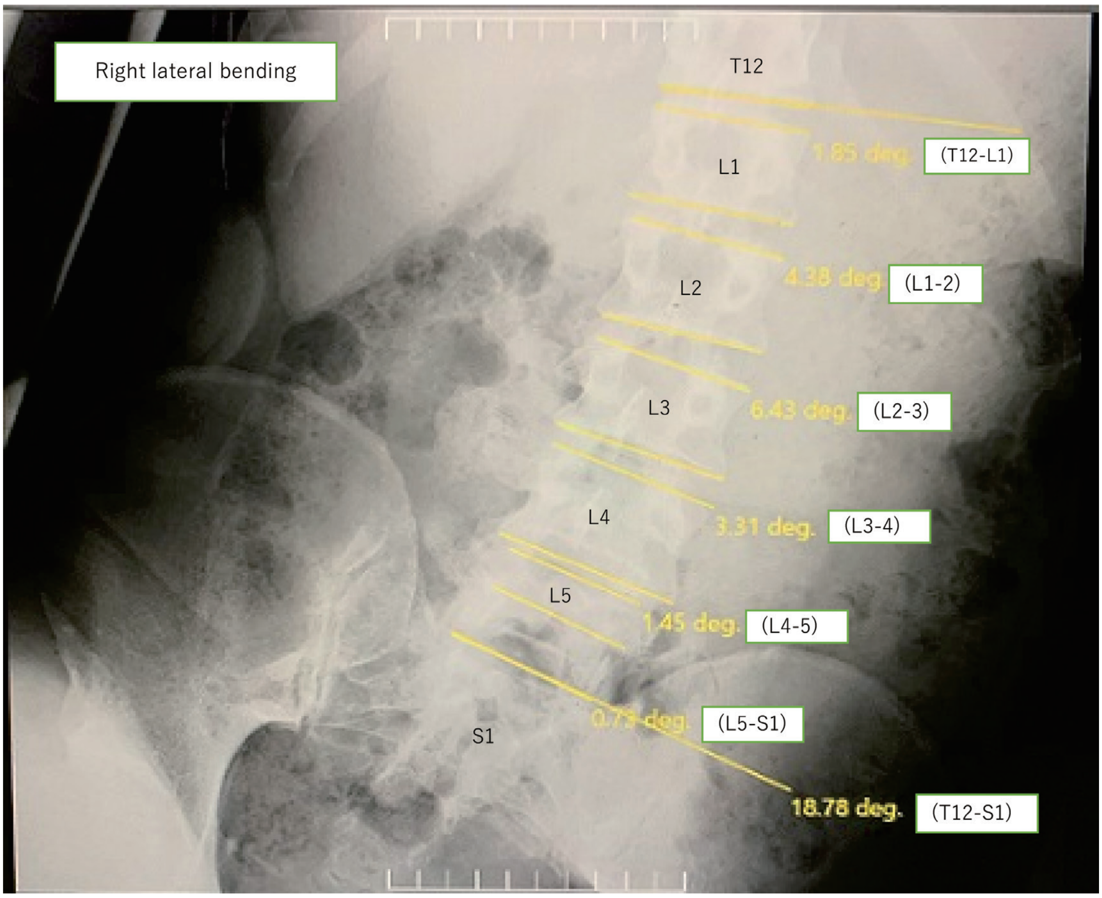

Fig. 2. Radiograph of lumbar spine with lateral bending
The yellow lines indicate each vertebral endplate and the angle between the cephalic and caudal endplates was measured as the intervertebral angle. Actual radiograph measurement image of lumbar spine.

hama, Japan) was used to measure the intervertebral ROLBs of each vertebral body endplate (Figure 2). The L5-S1 vertebral endplates were measured in alignment with the inferior border of the left and right L5 pedicles and the superior process of S1 since the endplates of the L5-S1 vertebral bodies are obscured due to lordosis. Since the number of lumbar vertebrae may vary due to transitional vertebrae, L5-L6 was measured as L5-S1 based on T12-L1. The average of the ROLBs measured by the three observers during left and right lateral bending was calculated as the measurement of the respective side. The second radiological measurement was performed two weeks after the first measurement to calculate inter- and intra-observer reliability. The main analysis used the data of the first measurement.

Statistical processing

Intraclass correlation coefficients were calculated using the first and second measurements of each observer to evaluate intra-rater reliability and correlation coefficients were calculated using the first measurements of the three observers to evaluate inter-rater reliability. Measurements of the L4-L5 level and the entire lumbar spine of T12-S1 were used as representative values to evaluate reliability.

For statistical analysis, the unpaired t-test was used for comparison between the two groups, and ANOVA followed by the Tukey-Kramer test was used for multiple comparisons. The correlation coefficient between age and intervertebral ROLB was calculated. Statistical processing was performed using JMP (ver. 15.0 ; SAS Institute Inc. Cary, NC). A difference of $P < 0.05$ was considered statistically significant.

Results

Four of the 82 subjects had missing data for L12-L1 due to incomplete imaging, but no subjects were excluded. The intra- and inter-rater reliability (intraclass correlation coefficients [2.1] and 95% confidence interval showed high reliability ranging from 0.93-0.99 (Tables 1 and 2). The results of this study yielded reference values for lateral bending intervertebral range of motion for each age group and gender (Table 3).

Evaluation by age group showed that the ROLB was larger in the 10-19, 20-29, and 30-39-year age groups, while it decreased with increasing age starting at 40 years. The overall ROLB of T12-S1 ± SD was : in males ; 18.0°± 2.0 in 10-19 years ; 21.0°± 3.0 in 20-29 years ; 21.5°± 3.1 in 30-39 years ; 18.5°± 2.4 in 40-49 years ; 15.2°± 2.5 in 50-59 years ; 15.1°± 2.3 in 50-59 years ; 8.2°± 3.3 in 70-79 years ; and 7.0°±1.2 in 80-89 years ; and in females, 23.6°± 2.3 in 10-19

Table1. Intra-assessor reliability (day 1-2 weeks later)

Examinee	Evaluation Item	ICC(1,2)	95% confidence interval	
			lower limit	upper limit
A	L4-5	0.96	0.93	0.97
A	T12-S1	0.99	0.98	0.99
B	L4-5	0.99	0.99	0.99
B	T12-S1	0.99	0.99	0.99
C	L4-5	0.93	0.89	0.95
C	T12-S1	0.98	0.96	0.99
	median	0.97	0.96	0.98

Table 2. 3 inter-rater reliability

Evaluation	ItemCC(2,1)	95% confidence interval	
		lower limit	upper limit
L4-5	0.94	0.83	0.98
T12-S1	0.98	0.96	0.99
median	0.96	0.89	0.99

Table 3. Mean and standard deviation of intervertebral range of motion by gender by age (deg)

	T12-L1			L1-L2			L2-L3			L3-L4		
	m/w total	man	woman	m/w total	man	woman	m/w total	man	woman	m/w total	man	woman
10s	2.9 (1.3)^{Bae}	2.0 (0.7)	3.9 (0.8)*	3.8 (1.1)^{ABa}	3.3 (1.2)	4.3 (0.8)	4.4 (1.1)^{ABe}	3.8 (1.0)	5.1 (0.7)	4.1 (1.1)^{ABb}	3.7 (1.0)	4.5 (1.2)
20s	2.3 (0.8)^{af}	1.9 (0.6)	2.7 (0.8)	3.3 (0.9)^{EFaf}	3.2 (1.2)	3.5 (0.4)	4.4 (1.0)^{EFaf}	4.7 (1.0)	4.1 (1.1)	4.5 (0.9)^{EFGaf}	4.5 (1.1)	4.5 (0.7)
30s	2.4 (0.5)^{acd}	2.1 (0.4)	2.6 (0.6)	3.7 (0.8)^{Jicd}	3.5 (0.8)	3.8 (0.9)	4.4 (0.9)^{IJc}	4.6 (0.7)	4.3 (1.2)	5.0 (1.1)^{IJLKd}	4.7 (1.4)	5.2 (0.7)
40s	2.3 (0.9)^{ac}	1.9 (0.6)	2.7 (1.1)	3.0 (0.5)^{a}	3.0 (0.7)	3.0 (0.3)	3.6 (0.9)^{c}	3.6 (0.8)	3.7 (1.1)	3.8 (0.8)^{c}	3.8 (0.8)	3.8 (1.0)
50s	2.2 (0.8)^{a}	2.0 (0.9)	2.3 (0.6)	2.8 (0.6)^{a}	2.8 (0.7)	2.9 (0.6)	3.4 (1.5)^{a}	2.8 (1.1)	4.0 (1.6)	3.1 (1.2)^{La}	2.4 (1.1)	3.8 (0.8)
60s	1.9 (0.7)^{e}	1.9 (0.8)	1.9 (0.7)	3.0 (1.1)^{a}	2.6 (1.3)	3.4 (0.7)	3.7 (1.6)^{e}	3.3 (1.0)	4.1 (2.1)	2.7 (0.9)^{GKa}	2.9 (1.0)	2.5 (0.7)
70s	1.6 (0.7)^{B}	1.3 (0.2)	1.9 (1.0)	1.9 (1.0)^{BFJa}	1.2 (0.2)	2.7 (0.8)*	2.7 (0.9)^{BFJa}	2.4 (0.3)	3.0 (1.2)	2.5 (1.1)^{BFJa}	2.6 (1.4)	2.5 (0.8)
80s	1.8 (0.7)	1.5 (0.8)	2.1 (0.6)*	2.3 (0.9)^{AEIa}	1.5 (0.4)	3.1 (0.5)*	2.4 (0.8)^{AEIa}	2.5 (0.9)	2.3 (0.9)	2.4 (1.6)^{AEIa}	1.6 (0.7)	3.2 (2.0)
total	2.2 (0.9)^{acf}	1.8 (0.7)	2.5 (1.0)*	3.0 (1.0)^{cf}	2.7 (1.1)	3.4 (0.8)*	3.7 (1.3)^{f}	3.5 (1.2)	3.8 (1.4)	3.8 (1.8)^{f}	3.3 (1.4)	3.8 (1.3)

	L4-L5			L5-S1			T12-S1		
	m/w total	man	woman	m/w total	man	woman	m/w total	man	woman
10s	2.5 (1.5)^{Meab}	2.0 (1.0)	3.0 (1.8)	0.6 (0.2)^{abe}	0.7 (0.2)	0.6 (0.1)	20.8 (3.6)^{ABDL}	18.0 (2.0)	23.6 (2.3)*
20s	3.5 (1.2)^{Eaf}	3.3 (1.3)	3.7 (1.2)	0.7 (0.1)^{af}	0.7 (0.1)	0.7 (0.1)	21.3 (3.2)^{GEFH}	21.0 (3.0)	21.6 (3.7)
30s	4.0 (1.4)^{IJMKc}	3.1 (1.4)	4.7 (1.1)	0.7 (0.2)^{acd}	0.6 (0.2)	0.8 (0.1)	22.5 (3.4)^{IJL}	21.5 (3.1)	23.3 (3.7)
40s	2.9 (0.7)^{a}	2.9 (0.5)	2.9 (0.9)	0.7 (0.4)^{ac}	0.5 (0.1)	0.8 (0.5)	18.8 (2.5)^{PON}	18.5 (2.4)	19.9 (2.7)
50s	2.5 (0.9)^{a}	3.1 (0.7)*	2.0 (0.8)	0.6 (0.1)^{a}	0.6 (0.2)	0.6 (0.1)	16.2 (2.7)^{DLHQ}	15.2 (2.5)	17.2 (2.7)
60s	2.1 (0.9)^{Kae}	2.3 (1.1)	2.0 (0.6)	0.7 (0.2)^{ae}	0.7 (0.2)	0.7 (0.2)	15.2 (2.6)^{LGJPSR}	15.1 (2.3)	15.3 (3.1)
70s	2.2 (0.9)^{Ja}	2.3 (0.9)	2.0 (1.0)	0.7 (0.1)^{a}	0.7 (0.1)	0.7 (0.1)	10.9 (4.0)^{BFJOQS}	8.2 (3.3)	13.6 (2.7)*
80s	1.9 (0.6)^{EI}	1.7 (0.4)	2.1 (0.7)	0.7 (0.2)^{a}	0.6 (0.0)	0.7 (0.3)	7.8 (2.0)^{AEINR}	7.0 (1.2)	8.5 (2.5)
total	2.7 (1.2)^{cf}	2.6 (1.1)	2.8 (1.4)	0.7 (0.2)^{acf}	0.7 (0.2)	0.7 (0.2)	16.7 (5.7)	15.7 (5.7)	17.9 (5.6)

* : Significant difference in ROLB between men and women.
A-S : Same capital letters indicate a significant difference among each age group in each level.
a-f : Same lowercase letters indicate a significant difference among each level in each age group.

years ; 21.7°± 3.7 in 20-29 years ; 23.3°± 3.7 in 30-39 years ; 19.1°± 2.7 in 40-49 years ; 17.2°± 2.7 in 50-59 years ; 15.3°± 3.1 in 60-69 years ; 13.6°± 2.7 in 70-79 years ; and 8.6°± 2.5 in 80-89 years. Significant negative correlations were found between age and ROLB of the entire lumber spine in both sexes ($p < 0.01$).

Comparing the ROLB of T12-S1 for males and females combined between the age groups, the ROLBs in the 10-19, 20-29, and 30-39 year age groups (21.0°± 3.6, 21.3°± 3.2, and 22.5°± 3.4 respectively) were significantly larger than those in the 50-59, 60-69, 70-79, and 80-89 year age groups (16.2°± 2.7, 15.2°±2.6, 10.9°± 4.0, and 7.8°± 2.0, respectively) ($p < 0.05$). The ROLB was significantly larger in the 40-49 year age group (18.8°± 2.5) compared to the 60-69, 70-79, and 80-89 year age groups ($p < 0.05$). The ROLB was significantly larger in the 50-59 and 60-69 age groups compared to those aged ≥ 70 years ($p < 0.05$) (Figure 3) (Table 3). Comparing the ROLB of each level among the age groups, the ROLB in L1-L2 was significantly larger in the 10-19 and 20-29 age groups compared to those aged over 70 years, while the ROLB in the 30-39 age groups was significantly larger than 80-89 age group. The ROLB in the 10-19, 20-29, and 30-39 age groups were significantly larger than those in the 70-79 and 80-89 age groups in L2-L3. The ROLB in the 10-19 age group was significantly larger compared to those aged over 70 years, while the ROLB in the 20-29 age group was larger compared to those aged over 60, and the ROLB in the 30-39 age group was larger compared to those age over 50 in L3-L4 ($p < 0.05$). The ROLB in the 30-39 age group was larger than that of the 10-19 age group and those aged over 60 years, and the ROLB in the 20-29 age group was larger than 80-89 group in L4-L5 ($p < 0.05$), while there was no significant difference among all age groups in L5-S1.

The ROLB between each level for all ages and sexes combined was 2.2°±0.9 for T12-L1, 3.0°±1.0 for L1-L2, 3.7°±1.3 for L2-L3, 3.8°±1.8 for L3-L4, 2.7°±1.2 for L4-L5 and 0.7°±0.2 for L5-S1.

When comparing the ROLB of each level, L2-L3 (3.7°) and L3-L4 (3.8°) each had significantly larger ROLB than T12-L1, L1-L2, L4-L5, and L5-S1, while L1-L2 (3.0°) and L4-L5 (2.7°) each had significantly larger ROLB than T12-L1 and L5-S1 (0.7°) ($p < 0.05$) (Figure 4). Comparing the ROLB among each level in each age group, in the 10-19 age group, the ROLB of L2-L3 was significantly larger than T12-L1, L4-5, and L5-S1, the ROLB of L3-L4 was larger than L4-L5 and L5-S1, while the ROLB of T12-L1, L1-L2, and L4-L5 were significantly larger than L5-S1. In the 20-29 age group, the ROLB of L2-L3 and L3-L4 were significantly larger than that of T12-L1, L1-L2, L4-L5, and L5-S1. The ROLB of L5-S1 was significantly smaller than all other levels, and the ROLB of T12-L1 was smaller than other groups except for L5-S1. In the 30-39 age group, the ROLB of T12-L1 was significantly larger than L5-S1. The ROLB of L3-L4 was significantly larger than T12-L1, L1-L2, and L5-S1. The ROLB of L1-L2, L2-L3, and L4-L5 were significantly larger than that of T12-L1 and L5-S1. In the 40-49 age groups, the ROLB of T12-L1,

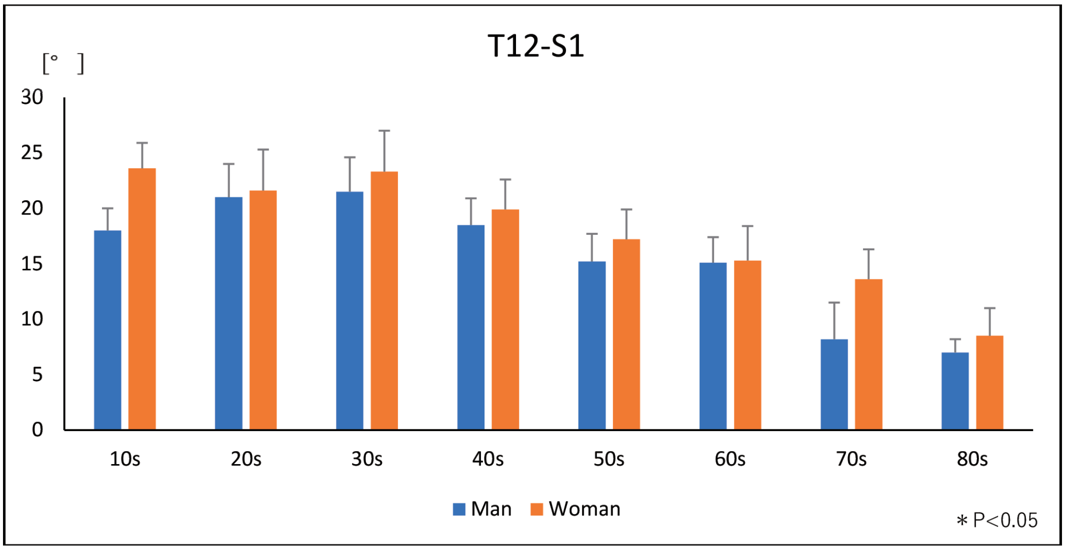

Fig. 3. T12-S range of lateral bending of each age group
There were no differences between men and women in any of the age groups. Significant differences between the two age groups are shown in Table 3.

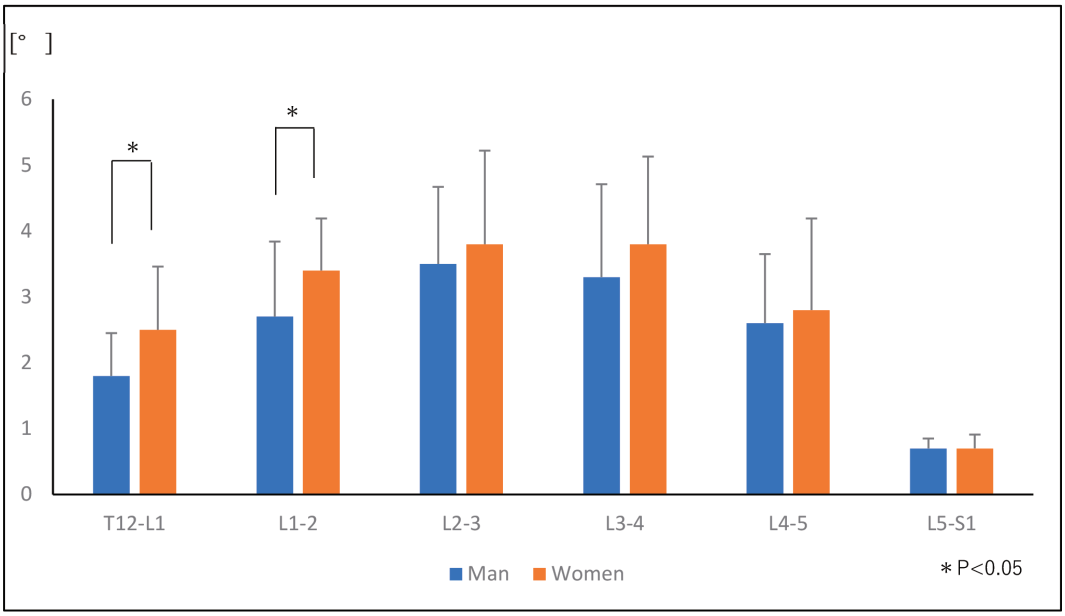

Fig. 4. Range of lateral bending of each level
There were significant differences between men and woman in T12-L1 and L1-L2.
Significant differences between each level are shown in Table 3.

L1-L2, and L4-L5 was significantly larger than L5-S1, and the ROLB of L2-L3 and L3-L4 were larger than T12-L1 and L5-S1 ($p < 0.05$). In the 50-59 age group showed significant differences between only L5-S1 and all other levels ($p < 0.05$). In the 60-69 age group, The ROLB of L1-L2, L3-L4, and L4-L5 was significantly larger than L5-S1. The ROLB of L2-L3 was significantly larger than T12-L1, L4-L5 and L5-S1. In the 70-79 age group, ROLB of L1-L2, L2-L3, L3-L4, L4-L5 was significantly larger than L5-S1 ($p < 0.05$). In the 80-89 age group, the ROLB of L1-L2, L2-L3, L3-L4 was significantly larger than L5-S1 ($p < 0.05$).

In the comparison of ROLB between the males and females for all age groups, the females had significantly larger ROLB than males at T12-L1 and L1-L2 ($p < 0.05$) (Figure 4) (Table 3). In comparison between gender in each age group and level, there were significant differences between males and females at T12-L1 and T12-S1 in the 10-19 age group, at L4-L5 in the 50-59 age group, and at L1-L2 in those over 70 years old (Table 3).

The correlation coefficients between age and ROLB of each level showed significant negative correlations at T12-L1 to L4-L5, but not at L5-S1, and T12-S1 also showed a significant negative correlation ($p < 0.001$) (Table 4).

Table 4. Correlation coefficient between all ages and vertebrae

intervertebral space	correlation coefficient	P-value
T12-L1	−0.42	<0.01*
L1-L2	−0.52	<0.01*
L2-L3	−0.54	<0.01*
L3-L4	−0.6	<0.01*
L4-L5	−0.41	<0.01*
L5-S1	−0.006	0.95
T12-S1	−0.82	<0.01*

Discussion

The present study clarified the preliminary reference values of the intervertebral range of motion during lateral bending of the lumbar spine in healthy subjects, by gender and age group as shown in Table 3. This value is considered to be an indicator of which vertebrae and how much they move during lumbar lateral bending exercise therapy. It may also be used as a criterion for determining pathological instability and reduced range of motion. This preliminary reference value needs to be validated in future studies with large sample sizes.

The correlation coefficients between age and ROLB in this study showed a significant negative correlation between age and ROLB of each level at T12-L1 to L4-L5 and the entire lumbar spine among T12-S1 ($p < 0.05$). In terms of gender, the ROLB was larger in those aged 10-39 years and there was a significant decrease in ROLB with aging for both females and males. No previous study has reported ROLB in the supine position separately for the age group. However, a systematic review of previous studies on ROLB in the standing position showed that ROLB significantly decreased with age in both sexes[12]. As for the reason for the decrease in ROLB with aging, it has been reported that age-related changes in fascial thickness may contribute to the limitation of joint range of motion[17].

Comparison of ROLB of each level between men and women showed that women had significantly larger ROLB than men at T12-L1 in the 10-19 age group, at L1-L2 in the 70-79 and 80-89 age groups, and T12-L1 and L1-L2 in all age group ($p<0.05$). On the other hand, the ROLB of L4-L5 was significantly larger in men in the 50-59 groups. In a previous study, ROLB in vivo in the supine position was studied, but due to the small number of subjects, the ROLB was not examined separately for men and women[15]. In an anatomical study evaluating lumbar lateral bending of spinal segments that were obtained from 42 cadavers with no history of treatment for spinal disease and placed in the supine position, the ROLB was significantly larger in women than in men[16]. A systematic review of ROLBs in the standing position reported no significant gender differences in the mean and respective ROLBs of the left and right sides in all age groups[12]. The results of this study suggest that the ROLB may be larger in females in the upper lumbar spine of young or elderly subjects. On the other hand, only the ROLB of L4-L5 was larger in males of the 50-59 age group. One possible explanation was due to the influence of L4 spondylolisthesis in females. The L4 spondylolisthesis is more frequent in middle-aged women, and the presence of spondylolisthesis may affect the ROLB. The lateral X-ray was not examined in this study, and further study is needed to clarify this point.

When comparing the ROLB of each level in all age groups, in the present study, the ROLB was the largest at L2-L3 and L3-L4, and the ROLB was significantly smaller at their cephalocaudal sides, especially at L5-S1. These findings were also found when comparing the ROLB of each level in each age group, and particularly evident in the 20-29 and 30-39 age groups. In previous report[14], L5-S1 had significantly smaller ROLB in the supine position compared to all the other levels. In addition, the ROLB at L1-L2 and L2-L3 were significantly smaller than that at L3-L4[14]. In a study by Cook *et al.* the ROLBs of L2-L3, L3-L4, and L4-L5 were significantly larger than those of L1-2 and L5-S1[16]. On the other hand, a previous study evaluated the ROLB in the standing position in subjects aged from 22 to 50 years, in which the ROLB was the largest at L2-L3 and L3-L4, which was similar to the results of the present study[13]. The reasons why the ROLB was smaller in the lower lumbar spine at L4-L5 and L5-S1 than in the upper levels were considered to be the greater load applied to the lower lumbar spine, the greater volume of the lower lumbar spine, and limited mobility by a strong fixation force of the iliolumbar ligament. The small ROLB of T12-L1 was considered to be due to T12-L1 being contiguous to the thoracic spine, which is less mobile, and thus its mobility is more limited than that of L2-L3 and L3-L4.

The results of the present study showed that the ROLB of T12-S1 across the lumbar spine was limited to less than 10° in men aged $\geq$ 70 years and in women aged $\geq$ 80 years. Lumbar lateral bending is used for lateral movement on the floor. Since such movement causes friction with the floor and involves lifting their own body weight, the elderly with a narrow ROLB may be restricted in their floor activities. Interventions to improve ROLB in such elderly patients are expected to improve their activity on the floor. Furthermore, the improvement of ROLB may contribute to the extensibility of trunk muscles such as the internal and external abdominal oblique muscles, which may have a positive effect on the respiratory function of the elderly.

One of the purposes of this study was to evaluate the characteristics of ROLB, especially at L4-5 and L5-S1 where lumbar disc herniation predominantly occurs, to clarify the effectiveness of lateral bending exercise therapy for lumbar disc herniation. Although lateral bending exercise therapy may not have much effect on L5-S1 with small ROLB in all age groups, it may have a beneficial effect on other levels, particularly for those aged from 20 to 40 with large ROLB. On the other hand, the effect of lateral bending exercise therapy is likely to be limited for patients aged $\geq$ 70 years with small ROLB in each level.

There are some limitations in this study. This is the problem of the accuracy of the radiographic measurements. Due to the lordosis of the lower lumbar spine, especially between the L5-S1 vertebrae, the end plates cannot be identified, so other bony structures (pedicles and facet joints) were used as a substitute. However, both intra- and inter-rater reliability of the ROLB were satisfactory. Although multiple radiological measurements with different angles of incidence to confirm the endplate of the lower lumbar spine may increase the accuracy, the number of measurements was minimized in the present study to reduce radiation exposure. One limitation is the small number of subjects in each age group. Another limitation is that we included healthy volunteers without back pain, but did not examine comorbidities or obesity. Since the results of this study were preliminary, further studies should include a larger study population to determine whether the results of this study are truly generalizable.

Conclusion

The results of this study revealed the preliminary reference values of ROLB in each gender and age group. Regarding the relationship between ROLB and age for each lumbar intervertebral level, significant negative correlations with age were found for all levels except L5-S1. The ROLB was large in the subjects aged from 10 to 30 years for the entire lumbar spine of T12-S1 and each level except that of L5-S1 for both males and females and decreased with age. In each level, the ROLB was the largest at L2-L3 and L3-L4, and smallest at L5-S1 in all age groups. Regarding gender differences, the ROLB was significantly larger in the females at T12-L1 and L1-L2.

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