The Relationship between Exercise-Induced Low Back Pain, the Fat Infiltration Rate of Paraspinal Muscles, and Lumbar Sagittal Balance

Masataka Nakamura, Koji Otani, Yota Kaneko, Miho Sekiguchi and Shin-ichi Konno

Department of Orthopaedic Surgery, Fukushima Medical University School of Medicine, Fukushima, Japan

Abstract:

Introduction: Exercise-induced low back pain (EILBP) is induced during anterior trunk tilting when walking or prolonged standing. In some elderly with chronic LBP, the pain is induced by EILBP. The paraspinal muscles play an important role in supporting the spine; therefore, a dysfunction of back muscles and kyphotic alignment are considered to be associated with EILBP. However, few reports are showing the relationship between EILBP and degenerative muscle changes. This study aimed to clarify the relationship between EILBP, degenerative changes of paraspinal muscles, and spinal alignment in an epidemiological study.

Methods: A total of 324 subjects were included in the analysis. The presence of EILBP was determined through a medical interview and physical examination. The subjects underwent lumbar spine magnetic resonance image (MRI) and X-ray. The fat infiltration rate (FIR) of the multifidus, erector spinae, and psoas major were analyzed using MRI. For lumbar sagittal balance, L1 axis S1 distance (LASD) was measured using X-ray images. Multivariate logistic regression analysis was used to analyze the association between the presence of EILBP and FIR or LASD.

Results: The prevalence of EILBP was 21% and it increased with age. The subjects with EILBP had statistically higher FIR of the multifidus, erector spinae, and psoas major than those without EILBP. There was a significant association between the presence of EILBP and higher FIR of the erector spinae at L1-2 and L5-S1 ($p<0.05$). However, there were no significant associations between EILBP and LASD.

Conclusions: According to the results in this study, EILBP is not rare and the FIR of the erector spinae is associated with the presence of EILBP.

Keywords:

low back pain, exercise-induced low back pain, fat infiltration rate, paraspinal muscle, lumbar sagittal balance

Spine Surg Relat Res 2022; 6(3): 261-270

dx.doi.org/10.22603/ssrr.2021-0103

Introduction

Low back pain (LBP) is one of the most prevalent conditions among the general population, and it decreases quality of life (QOL). The pain is caused by various factors, and it is not often specified[1,2]. Exercise-induced low back pain (EILBP) is defined to be induced LBP during anterior trunk tilting when walking or prolonged standing[3]. In some elderly with chronic LBP, the pain is induced by EILBP and it is not a rare symptom. This kind of chronic LBP has also been reported under the name motion-induced intermittent LBP (MILBP) and intermittent claudication due to LBP[3-5]. They are considered the same entity. Patients with EILBP occur in a progressively anterior trunk tilting posture while standing or walking, consequently, cause to LBP. The pain is relieved by lumbar extension and it is asymptomatic or mild pain at rest (Fig. 1). Moreover, there are no symptoms in the lower extremities[3,4]. One of the causative factors of EILBP is chronic compartment syndrome in the muscles of the lumbar spine[3].

The paraspinal muscles play an important role in supporting the spine during walking and exercising[6,7]; therefore, a dysfunction of back muscles is considered to be associated with EILBP. In addition, anterior trunk tilting induced by kyphotic alignment may cause EILBP. It has been reported that degenerative changes of the paraspinal muscles such as

Corresponding author: Koji Otani, kotani@fmu.ac.jp
Received: May 19, 2021, Accepted: September 8, 2021, Advance Publication: November 4, 2021

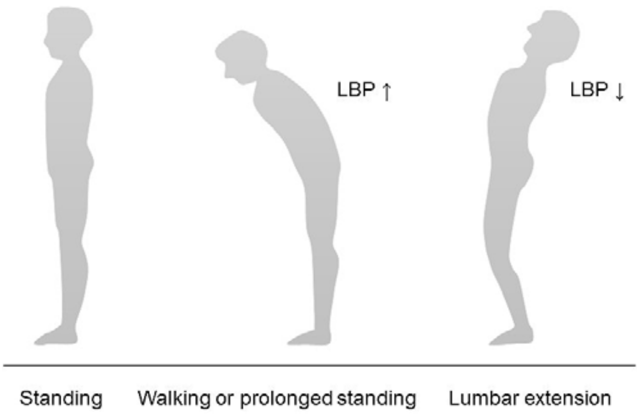

Figure 1. Association with postural change and pain in EILBP.
Anterior trunk tilting posture while walking and prolonged standing is the cause of pain. The pain is relieved by lumbar extension.
Abbreviations: LBP, low back pain; EILBP, exercise-induced low back pain

fat infiltration and muscle atrophy were related to LBP[8]; however, few reports are showing the relationship between EILBP and degenerative muscle changes.

The purpose of this study was twofold. The first was to investigate the prevalence of EILBP. Another was to clarify the relationship between EILBP, degenerative changes of paraspinal muscles using magnetic resonance image (MRI), and lumbar sagittal balance in an epidemiological study.

Materials and Methods

This study was approved by the ethics committees of our university. All subjects provided written informed consent.

A total of 324 subjects (103 men, 221 women; mean age, 64 years; age range, 27-86 years) who agreed with the purpose of the study in 2004 were enrolled. They had a medical interview and physical examination and underwent a lumbar spine MRI scan. Of 324 subjects, 264 (81.5%) were available for the lateral view of a neutral standing lumbar X-ray scan. All 324 subjects comprised residents in mountainous areas of Fukushima Prefecture, Japan. Subjects were excluded if they were unable to walk independently, fill out questionnaires due to visual impairment, had ever undergone brain or spinal surgery, or had suffered a fracture of the lower extremities in the year before the study period[9]. The subjects filled out questionnaires as follows. The Roland-Morris Disability Questionnaire (RDQ; Japanese version) and the MOS 36-Item Short-Form Health Survey (SF-36; Japanese version) were used to measure LBP- and health-related QOL[10-12]. In this study, the norm-based score of the RDQ and SF-36 were used to facilitate the comparison, because the unadjusted scores were remarkably different in sex and age. These norm-based scores are adjusted for sex and age and range from 20 to 79 years old and 50 points as the mean score and a standard deviation of 10 points. Fifty points or more represents a good QOL, and less than 50 points represent a low QOL[13,14].

Criteria of EILBP[3-5] and LBP

The subjects were divided into three groups: absence of LBP, LBP (−) group; presence of LBP without EILBP, LBP (+) group; and presence of EILBP, EILBP (+) group. LBP was determined by the presence or absence of back pain that lasted more than 24 h by self-assessment. The presence of EILBP was determined through a medical interview and examination by a board-certificated spine specialist (KO). EILBP was determined as follows: (1) back pain induced by anterior trunk tilting posture while standing or walking, (2) pain relieved by lumbar extension, (3) asymptomatic at rest, and (4) no detectable neurologic deficits of the lower extremities. All items that did not meet this criterion were determined to be without EILBP. The numerical rating scale (0, no pain; 10, the worst pain imaginable) was used to measure the degree of LBP.

Measurement of MRI and radiologic parameters

The fat infiltration rate (FIR) and cross-sectional area (CSA) of the multifidus, erector spinae, and psoas major were assessed as follows. Axial T2-weighted images were obtained at the midpoint of each intervertebral disc from L1-2 to L5-S1 (Supplement 1). The FIR and CSA were measured using an image processing software (Image J; National Institutes of Health, Bethesda, MD, USA) by manually drawing the fascial boundary of the bilateral multifidus, the erector spinae, and the psoas major (Fig. 2-a). FIR was measured using the method by Ranson et al.[15]. It was measured by setting the gray-scale threshold for the fat tissues and measuring the pixels above that threshold (Fig. 2-b). The mean of the bilateral FIR and CSA were analyzed. Since CSA of the paraspinal muscle is highly influenced by body size, we calculated the ratio of the CSA to the height of body (CSA/height). The average values of L1-2 to L5-S1 were calculated.

We measured the degenerative disk disease (DDD) score[16], which is the sum of the Schneiderman classification from L1-2 to L5-S1. We also measured the Modic change[17] from L1-2 to L5-S1.

As an index for the radiologic evaluation of lumbar sagittal alignment, this study used the L1 axis S1 distance (LASD), lumbar lordosis (L1-L5), and sacral slope[18]. LASD is the horizontal distance from the plumb line of the center in the L1 lumbar vertebral to the back corner of the S1 vertebral body (Fig. 2-c). This was measured on lateral radiographs of subjects in a neutral standing position.

To evaluate intra-observer reliability, 30 randomly selected MR images and X-ray images were measured two times by the same observer with a 1-month interval. The intra-observer correlation of the FIR was 0.965 ($p<0.001$, 95% CI: 0.952-0.974), CSA 0.981 ($p<0.001$, 95% CI: 0.973-0.986), LASD 0.990 ($p<0.001$, 95% CI: 0.980-0.995), lumbar lordosis 0.969 ($p<0.001$, 95% CI: 0.935-0.985), sacral

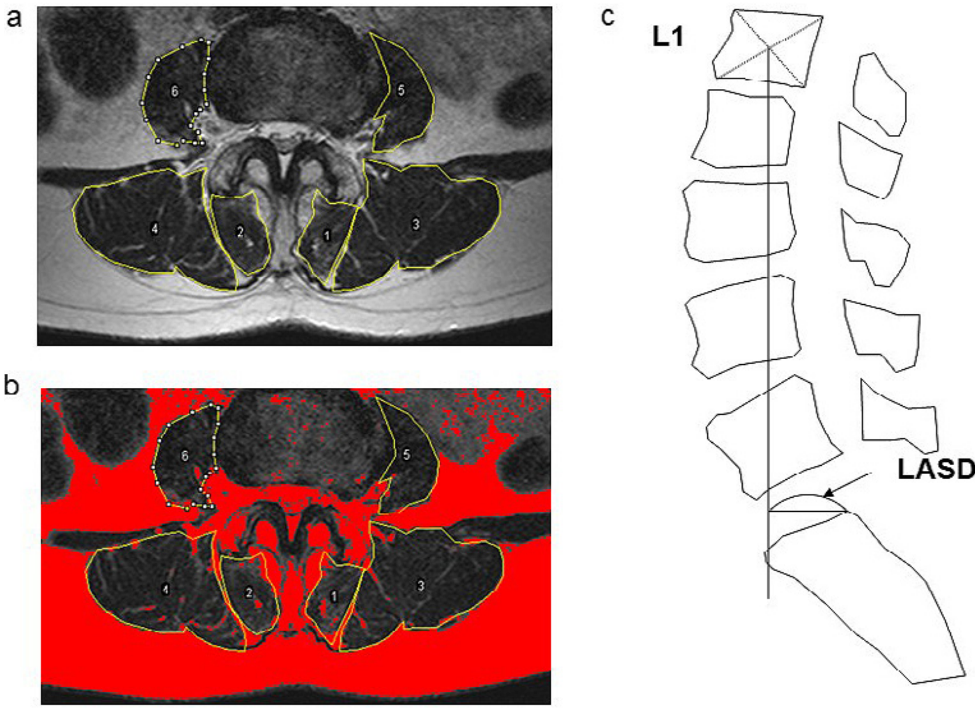

Figure 2. Measurement for fat infiltration rate and cross-sectional area of paraspinal muscles and L1 axis S1 distance.

This figure shows the L3-4 intervertebral disc level as the example.

a; The area surrounded by the yellow line was the cross-sectional area of each muscle.

b; The region of red color represents high intensity area, and it was defined as the fatty infiltration area. (1, 2, multifidus; 3, 4, erector spinae; 5, 6, psoas major).

c; This figure shows the lumbar lateral radiographs. L1 axis S1 distance is the horizontal distance from the plumb line of the center in the L1 lumbar vertebral to the back corner of the S1 vertebral body.

Abbreviations: LASD, L1 axis S1 distance

slope 0.930 ($p<0.001$, 95% CI: 0.859-0.966), DDD score 0.774 ($p<0.05$), and Modic change 0.738 ($p<0.05$).

Statistical analysis

The Chi-square test, the Kruskal-Wallis test, or the Mann-Whitney U test was used to compare demographic characteristics, norm-based SF-36 score (eight domain), and MRI and radiologic parameters between LBP (−) group, LBP (+) group, and EILBP (+) group. The Dunn-Bonferroni test was used between every two groups after the Kruskal-Wallis test. The Chi-square test or the Mann-Whitney U test was used to compare NRS, norm-based RDQ score, and walking disability from RDQ and SF-36 questionnaire between LBP (+) group and EILBP (+) group. FIR values of the paraspinal muscles were also compared between sexes. The Jonckheere-Terpstra test was used to identify paraspinal muscle FIR trends in age. Multivariate logistic regression analysis, adjusting for age, sex, and body mass index (BMI), was used to analyze the association between the presence of EILBP and related factors. In this analysis, the presence and the absence of EILBP was used as the objective variable, and the FIR of the multifidus, erector spinae, and psoas major and LASD were used as explanatory variables. Each disk level from L1-2 to L5-S1 of FIR was analyzed. Receiver operating characteristic (ROC) curves were drawn from the significant variables and EILBP, and cutoff values were obtained.

All analyses were performed using SPSS (IBM SPSS statistics 26, IBM, Armonk, NY, USA), and p values of <0.05 were considered statistically significant. Data are presented as proportions and means (±standard deviation: SD).

Results

Demographic characteristics

The differences in demographic characteristics among three groups were shown in Table 1. There were 68 subjects (21.0%) with EILBP, of whom 15 (22.1%) were men and 53 (77.9%) were women, and 23 subjects were in LBP (+) group (that have LBP but not EILBP), 224 were in LBP (−) group, and 9 did not answer the LBP presence. There were no statistical differences in the proportion of sex, BMI, LASD, and DDD score among the three groups. However, EILBP (+) group was statistically older than the other groups. The prevalence of EILBP in each age group is

Table 1. Differences in Demographic Characteristics and Image Parameters in LBP (−), LBP (+), and EILBP (+).

	LBP (−) n=224	LBP (+) n=23	EILBP (+) n=68	p value
Sex men/women	72/152	11/12	15/53	0.058
Age (years)	62.9±11.2	60.2±13.2	69.8±10.1	<0.001
Body mass index (kg/m^2)	22.9±3.0	23.2±2.7	23.4±2.8	0.475
SF-36 norm-based score				
Physical functioning	50.4±11.9	54.4±9.2	46.4±9.4	<0.001
Role-physical	48.7±11.3	50.9±7.9	45.7±10.5	0.049
Bodily pain	47.8±10.5	45.6±9.9	43.5±8.6	0.018
General health	47.7±8.4	42.8±8.1	46.2±8.8	0.017
Vitality	50.7±9.2	51.4±8.1	50.0±8.7	0.850
Social functioning	50.7±9.4	49.1±10.7	50.9±8.5	0.752
Role-emotional	49.5±10.2	50.5±9.1	48.1±11.3	0.756
Mental health	47.8±9.5	46.0±9.9	48.1±11.0	0.532
Average CSA (mm^2)				
Multifidus	859.2±200.0	889.2±210.1	757.8±198.1	<0.001
Erector spinae	2507.5±557.1	2602.8±600.7	2362.6±641.2	0.085
Psoas major	1210.0±445.4	1376.2±568.8	1025.8±349.3	0.002
Average CSA/height (mm^2/cm)				
Multifidus	5.5±1.2	5.3±1.2	4.9±1.1	<0.001
Erector spinae	16.2±3.5	15.7±3.1	15.4±4	0.388
Psoas major	7.6±2.5	7.1±2.7	6.6±2.0	0.013
Average FIR (%)				
Multifidus	16.3±12.6	14.5±9.1	26.3±16.3	<0.001
Erector spinae	10.9±9.2	8.9±5.9	18.5±11.0	<0.001
Psoas major	2.4±1.7	2.2±2.3	3.5±2.3	<0.001
LASD (mm)	13.5±14.3	11.2±15.5	8.5±20.2	0.137
Lumbar lordosis (L1-5) (°)	30.7±11.9	31.6±11.8	23.4±12.0	<0.001
Sacral slope (°)	35.8±8.0	36.5±8.4	29.5±8.8	<0.001
DDD score	8.7±3.2	7.7±3.3	10.0±3.4	0.222

Data are shown as n or as mean±standard deviation. Average FIR and CSA are the average value of L1-2 to L5-S1. Average CSA/height=average (L1-2 CSA/height to L5-S1 CSA/height)
LBP (−), absence of low back pain; LBP (+), presence of LBP without EILBP; EILBP (+), presence of EILBP.
A total of 264 subjects were available for X-ray scan, of whom 54 were subjects with EILBP.
Abbreviations: SF-36, MOS 36-Item Short-Form Health Survey; EILBP, exercise-induced low back pain; FIR, fat infiltration rate; CSA, cross-sectional area; LASD, L1 axis S1 distance; DDD, degenerative disc disease

shown in Fig. 3. It tended to increase with age in both sexes. The prevalence of EILBP was statistically significantly higher in women than in men in the age groups 65-74 and 75 years and older.

The norm-based SF-36 score [physical functioning, role-physical (RP), and bodily pain] was statistically lower in EILBP (+) group than in the other groups (Table 1). The average FIR of the multifidus, erector spinae, and psoas major muscles were statistically higher in the EILBP (+) group than in the other groups. The average CSA and CSA/height of the multifidus and psoas major muscles were statistically lower in the EILBP (+) group than the other groups. The lumbar lordosis and sacral slope were statistically lower in the EILBP (+) group than in the LBP (−) group. There were 18 (27.7%) who had Modic change at L4-5 among the EILBP (+) group, and the proportion of type of Modic change was statistically different and the proportion of the presence of Modic change was higher than the other groups (Supplement 2).

Although there was no statistical difference in NRS between the LBP (+) group and EILBP (+) group, norm-based RDQ score was statistically lower in the EILBP (+) group than in the LBP (+) group (Table 2). The walking disability from RDQ and SF-36 was also shown in Table 2. In EILBP (+) group, walking disability was statistically severer than in LBP (+) group (in the Japanese version of the SF-36, a mile in the original version was translated to a kilometer).

FIR of the paraspinal muscles and LASD

FIR was statistically lower in men and at all intervertebral disc levels except for erector spinae at L4-5 and psoas major at L5-S1. FIR tended to increase with age at all intervertebral disc levels except for psoas major at L1-2 and L5-S1 (Table 3). FIR of the multifidus and erector spinae tended to increase from L1-2 to L5-S1. FIR of the multifidus was statistically higher than the erector spinae except at L2-3. FIR

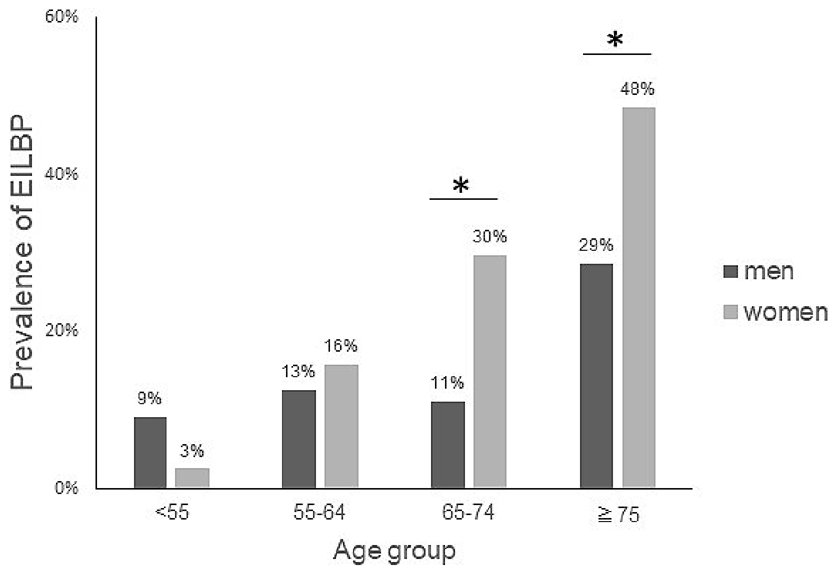

Figure 3. Prevalence of subjects with EILBP.
The prevalence of subjects with EILBP increased with age.
Abbreviations: EILBP, exercise-induced low back pain
*p<0.05

Table 2. Differences in NRS, RDQ Norm-Based Score, and Walking Disability in LBP (+) and EILBP (+).

	LBP (+) n=23	EILBP (+) n=68	p value
NRS	5.6±2.1	5.7±2.3	0.936
RDQ norm-based score	51.9±6.3	45.7±9.3	0.005
RDQ Q3. I walk more slowly than usual because of my back.			
Yes	7	48	<0.001
No	15	16	
RDQ Q17. I only walk short distances because of my back.			
Yes	4	42	<0.001
No	18	23	
SF-36 Limitations of activities			
Walking more than 1 km			
Yes, Limited a lot	0	13	<0.001
Yes, Limited a little	5	30	
No, Not Limited at all	18	17	
Walking several hundreds of meters			
Yes, Limited a lot	0	9	0.020
Yes, Limited a little	5	23	
No, Not Limited at all	18	28	
Walking about 100 m			
Yes, Limited a lot	0	2	0.044
Yes, Limited a little	1	16	
No, Not Limited at all	22	42	

Data are shown as n or mean±standard deviation.
LBP (+), presence of LBP without EILBP; EILBP (+), presence of EILBP.
Abbreviations: NRS, numerical rating scale; RDQ, Roland-Morris Disability Questionnaire; SF-36, MOS 36-Item Short-Form Health Survey; EILBP, exercise-induced low back pain

of the psoas major was statistically lower than the multifidus and erector spinae (Fig. 4).

Factors related to EILBP

In this analysis, LASD was selected as one of the explanatory variables because lumbar kyphosis may be associated with EILBP. However, there were no significant associations between EILBP and LASD in any analysis. Sex and BMI also showed no significant association with EILBP. On the other hand, there was a significant association between EILBP and FIR of erector spinae at L1-2 or L5-S1. The odds ratios of the erector spinae FIR were 1.041 (95% CI: 1.011-1.072) at L1-2 and 1.048 (95% CI: 1.007-1.090) at L5-S1 (Table 4). These results showed that EILBP might be associated with FIR of the erector spinae at L1-2 and L5-S1. ROC curves were drawn from the FIR of the erector spinae and EILBP (Fig. 5). The area under the curve (AUC) of the ROC curve was 0.767 (95% CI: 0.697-0.837) at L1-2 and 0.631 (95% CI: 0.553-0.710) at L5-S1. The AUC of the ROC curve was acceptable for L1-2, while L5-S1 was poorly discriminated[19]. Table 5 shows the cutoff value and statistical accuracy with sensitivity or specificity of around 0.8 and Youden index[20].

Discussion

There are three findings in this present study. First, we showed the prevalence of EILBP. Although we did not research on the study about the duration of EILBP, the results of the questionnaires showed that EILBP had an impact on QOL. Second, the FIR of the erector spinae in the subject with EILBP was statistically higher than those without EILBP. Third, sagittal alignment of the lumbar spine does not directly affect the presence of EILBP. There were the previous studies that have measured FIR from MRI images

Table 3. Differences in FIR in Sex and Age Groups.

	Sex			Age				
	Men	Women	p-value	<55	55–64	65–74	≥75	p-value
Multifidus								
Average	16.2±14.0	21.9±16.1	<0.001	9.4±8.6	16.1±12.6	22.9±15.8	28.4±17.2	<0.001
L1-2	13.0±14.0	19.4±17.9	<0.001	7.4±9.8	16.1±16.1	19.3±17.5	23.7±17.6	<0.001
L2-3	13.3±15.7	18.3±17.5	<0.001	6.9±9.0	13.8±13.6	18.9±17.6	24.2±20.1	<0.001
L3-4	14.7±15.1	19.9±17.8	<0.001	7.7±8.7	14.9±13.6	20.2±16.7	27.1±20.8	<0.001
L4-5	18.6±16.7	24.6±19.1	<0.001	11.7±10.5	18.3±15.1	26.3±19.2	29.7±20.8	<0.001
L5-S1	21.3±16.7	27.3±18.9	<0.001	15.5±12.7	21.7±15.9	28.1±19.0	32.8±19.5	<0.001
Erector spinae								
Average	11.3±9.1	15.5±13.3	<0.001	8.0±6.7	11.4±9.5	15.2±12.6	20.8±14.8	<0.001
L1-2	8.4±9.2	15.9±18.6	<0.001	5.0±4.7	10.5±11.9	14.8±17.1	21.5±21.3	<0.001
L2-3	8.7±9.0	13.6±15.9	0.002	5.4±5.8	9.6±9.9	13.1±15.2	18.3±17.8	<0.001
L3-4	9.5±8.6	13.3±12.9	0.002	6.7±6.3	10.0±8.5	12.9±11.9	17.3±15.4	<0.001
L4-5	12.2±10.5	14.2±12.1	0.072	8.1±7.1	11.7±10.7	14.7±11.5	18.2±13.6	<0.001
L5-S1	17.8±14.3	20.8±15.2	0.015	15.2±13.2	18.3±13.3	20.5±14.9	24.3±16.8	<0.001
Psoas major								
Average	2.0±1.5	2.9±2.0	<0.001	1.8±1.3	2.4±1.7	2.9±2.0	3.2±2.3	<0.001
L1-2	2.0±2.1	2.7±2.4	0.003	2.3±2.4	2.6±2.3	2.4±2.1	2.9±2.9	0.199
L2-3	1.6±1.6	2.5±2.2	<0.001	1.5±1.5	2.4±2.3	2.2±2.1	2.6±2.2	0.004
L3-4	1.8±1.4	2.8±2.5	<0.001	1.6±1.4	2.5±2.3	2.7±2.6	2.9±2.0	<0.001
L4-5	1.7±2.0	2.5±2.6	<0.001	1.4±1.2	2.0±1.8	2.7±3.0	2.7±2.8	<0.001
L5-S1	3.5±5.3	4.0±4.7	0.184	2.6±3.0	2.9±2.8	4.5±5.5	5.1±6.5	0.066

Data are shown as mean±standard deviation. Average is the average value of L1-2 to L5-S1.
Abbreviations: FIR, fat infiltration rate

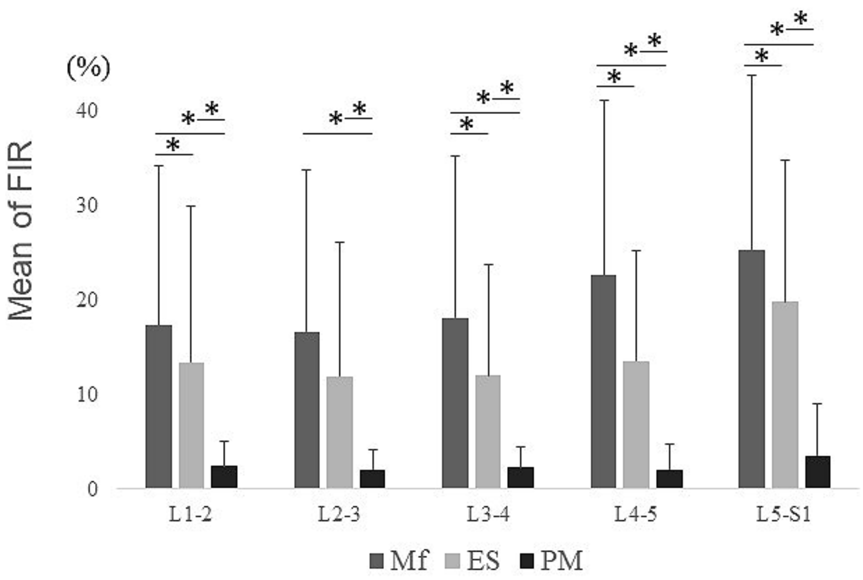

Figure 4. FIR of paraspinal muscles.
Abbreviations: FIR, fat infiltration rate; Mf, multifidus; ES, erector spinae; PM, psoas major
*p<0.05

using the same method as the present study and shown the relationship between FIR of the erector spinae muscles and LBP[8,21]. This was the first study to focus specifically on EILBP among rather LBP, which is thought to include a variety of pathologies. We clarified its prevalence and analyzed the relationship between EILBP and FIR of paraspinal muscles and lumbar sagittal balance.

We try to discuss the possible mechanisms of fat degeneration of the erector spinae muscle and EILBP based on the present study. The paraspinal muscles, which consist of the multifidus and erector spinae, are the muscles that support the spine, and there are many reports that their dysfunc-

Table 4. Factors Related to EILBP in Multivariate Logistic Regression Analysis at FIR of Each Disc Level.

		L1-2			L2-3			L3-4			L4-5			L5-S1		
		OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
Age (years)		1.056*	1.007	1.107	1.064*	1.015	1.116	1.067*	1.018	1.119	1.058*	1.008	1.110	1.080*	1.023	1.140
Sex	Women	Ref.			Ref.			Ref.			Ref.			Ref.		
	Men	0.670	0.282	1.590	0.613	0.262	1.432	0.573	0.246	1.333	0.580	0.249	1.351	0.658	0.259	1.672
BMI		1.079	0.951	1.226	1.090	0.964	1.233	1.093	0.968	1.235	1.087	0.959	1.231	1.120	0.977	1.283
FIR	Mf	1.005	0.977	1.033	1.012	0.982	1.042	0.998	0.966	1.032	1.016	0.992	1.042	0.993	0.961	1.025
	ES	1.041*	1.011	1.072	1.028	0.997	1.060	1.029	0.988	1.070	1.032	0.994	1.072	1.048*	1.007	1.090
	PM	1.106	0.965	1.269	1.100	0.947	1.277	1.085	0.938	1.255	1.022	0.898	1.162	1.002	0.932	1.078
LASD		0.994	0.971	1.017	0.990	0.968	1.013	0.988	0.966	1.010	0.990	0.968	1.012	0.984	0.961	1.008

Abbreviations: EILBP, exercise-induced low back pain; FIR, fat infiltration rate; OR, odds ratio; CI, confidence interval; BMI, body mass index; Mf, multifidus; ES, erector spinae; PM, psoas major; LASD, L1 axis S1 distance
*p<0.05

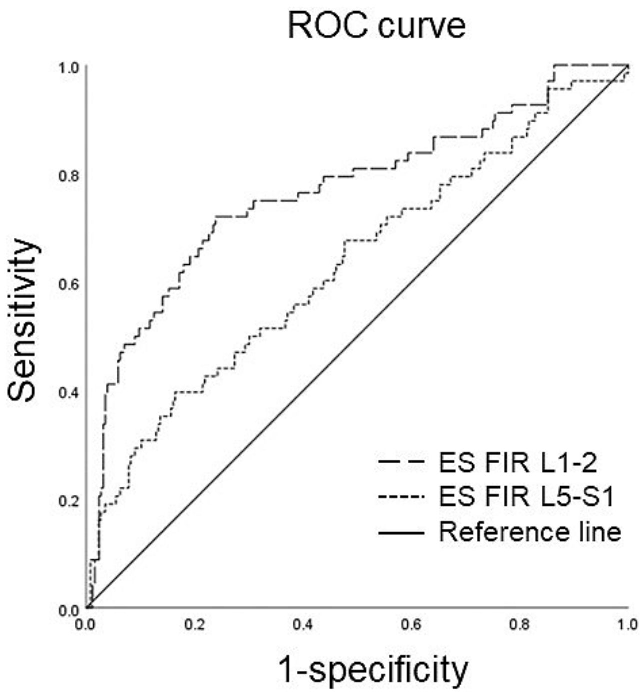

Figure 5. ROC curves of EILBP and the FIR of erector spinae.
The AUC of the ROC curve was acceptable for L1-2, while L5-S1 was poorly discriminated.
Abbreviations: ROC, receiver operating characteristic; EILBP, exercise-induced low back pain; FIR, fat infiltration rate; AUC, area under the curve; ES, erector spinae

tion and fatigue are associated with LBP and EILBP[21-23]. Furthermore, the difference between the multifidus and erector spinae muscles may be due to their different anatomical characteristics. One anatomical feature of the erector spinae is that the muscles act directly on the thorax and pelvis, acting as a global system that regulates movement throughout the spine while maintaining balance with the external loads on the trunk. On the other hand, the multifidus directly attaches to the lumbar spine and acts as a local system involved in local regulations such as lumbar lordotic curvature and intervertebral stability[6,7]. Normally, the local system acts predominantly during walking and posture maintenance, and the global system acts less. Contrary to reports on patients with chronic LBP and adult spinal deformity, the importance of the erector spinae during walking and posture maintenance has been reported. For example, Takahashi et al.[4] reported that using surface electromyography, MILBP, which is clinically similar to EILBP, causes anterior trunk tilting posture and muscle fatigue in the erector spinae muscle while standing. Banno et al.[24] also investigated the association between trunk tilt angle and paraspinal muscles in patients with adult spinal deformity and reported that trunk tilt angle correlated with the CSA of the multifidus muscle in the standing posture with relaxing and increased trunk tilt angle during walking correlated with the cross-sectional area of the erector spinae muscle. Among the elderly with EILBP, anterior trunk tilting posture may occur, and the erector spinae muscles can be excessively loaded to maintain posture[24].

Especially in the present study, this fat degeneration of the erector spinae muscle, one of the global systems that work to maintain posture, was statistically found at L1-2 and L5-S1 disk level. Each disk level from L1-2 to L5-S1 of FIR was analyzed because FIR is not uniform and varying with each disk level. The L1-2 and L5-S1 of erector spinae muscles may play an important role for patients with EILBP. The L1-2 and L5-S1 of the erector spinae muscles are close to the thoracic cage and pelvis and may be subjected to greater mechanical stress. In the point of AUC of the ROC curve, FIR of erector spinae at L1-2 is able to determine EILBP more accurately than L5-S1 because the AUC of the ROC curve was 0.767 at L1-2 and 0.631 at L5-S1. Therefore, FIR of erector spinae at L1-2 might be better associated with EILBP rather than that at L5-S1. In any case, FIR of erector spinae is particularly important for the pathophysiology of EILBP.

In the EILBP (+) group, the lumbar lordosis and sacral slope were lower than those in the other groups. Walking disability was also increased in the subjects with EILBP. The psoas major attaches to the lateral aspect of the lumbar spine and contributes to the acquisition of lumbar lordosis

Table 5. Cutoff Values, Sensitivity, Specificity, and Statistical Accuracy of ES FIR for EILBP.

	Cutoff value (%)	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy
L1-2 ES FIR	5.0	0.809	0.504	0.301	0.908	0.565
	6.0	0.779	0.562	0.321	0.906	0.608
	10.6 (Youden index)	0.721	0.762	0.441	0.911	0.750
	12.0	0.647	0.793	0.454	0.894	0.762
	13.0	0.632	0.812	0.467	0.892	0.772
L5-S1 ES FIR	9.0	0.809	0.273	0.228	0.843	0.386
	10.0	0.779	0.336	0.238	0.851	0.429
	23.0	0.412	0.781	0.341	0.837	0.707
	24.0	0.397	0.801	0.346	0.833	0.716
	25.0 (Youden index)	0.397	0.826	0.391	0.839	0.744

The cutoff values were calculated using the sensitivity around 0.8, the specificity around 0.8, and the Youden index.
Abbreviations: EILBP, exercise-induced low back pain; FIR, fat infiltration rate; ES, erector spinae

and stability of the lumbar spine[7]. In addition, the psoas muscle is responsible for flexing the hip joint, and it is also reported that the CSA of the psoas major was significantly correlated with walking speed[25]. So the psoas major muscle atrophy, which is one of the degenerative changes, may cause the walking disability and loss of lumbar lordosis and relate to EILBP. However, there was no relationship between EILBP and the FIR of psoas major, which is also one of the degenerative changes, in the logistic regression analysis in this study. Walking disability and loss of lumbar lordosis in EILBP subjects may not be directly related to atrophy of the psoas muscle.

Jackson et al.[26] reported that the C7 plumb line, which is thought to reflect the axis of loading, passes most frequently through the L1 vertebral body in a group of patients with LBP and most frequently through the L1-2 intervertebral disc in healthy volunteers. Therefore, the LASD, used as a measure of lumbar sagittal balance, is also thought to reflect the axis of loading. Since the lumbar lordotic angle and sacral slope in the standing position may not justify the compensatory effects of the pelvis and thoracic spine, the LASD, an index of the sagittal plane balance of the lumbar spine, was used in this study. This study was unable to detect a direct relationship between EILBP and lumbar sagittal balance evaluated by LASD. The results of this study may be helpful in the examination and treatment of elderly patients with chronic LBP. Because even if there is no change in sagittal balance of the lumbar spine at rest, the anterior trunk tilting during prolonged standing and walking in some elderly patients with muscle weakness, and that could cause the pain. When the lumbar muscles are continuously stressed by walking or loading, the high muscle discharge amplitude and muscle fatigue occur and cause anterior trunk tilting posture, intramuscular pressure increasing, and ischemic symptom progression. The patient becomes aware of pain in the lumbosacral spine[3,4,27-31]. This pain is called ischemic pain of the paraspinal muscles. And as a result, the paraspinal muscles become fat degeneration. If this vicious cycle continues, it might lead to more fat degeneration and cause further anterior trunk tilting posture (Fig. 6).

The cutoff values for EILBP by ES FIR were calculated with sensitivity and specificity priorities, respectively (Table 5). The cutoff values for the sensitivity of 0.8 or higher were 5.0% for L1-2 and 9.0% for L5-S1. The cutoff values for the specificity of 0.8 or higher were 13.0% for L1-2 and 24.0% for L5-S1. These values might be used as a screening or diagnostic indicator of the involvement of EILBP in the LBP that the patient is complaining about.

This has several limitations. First, this is a cross-sectional study; therefore, the natural history of paraspinal muscle degeneration and any causal associations with EILBP could not be established. Second, global spinal alignment and change of spinal alignment during prolonged standing and walking could not be measured. This study was in 2004, before Schwab's concept of global alignment was introduced, and parameters of the whole spine and pelvic were not measured. Only the radiographs in a neutral standing position may be inadequately assessed. Finally, it may be difficult to determine when the fat degeneration of the muscle becomes too high, the measurement error may occur larger due to the fascial boundaries of muscles. Although this study has some limitations described as above, we believe that the results of this study regarding EILBP and FIR of the paraspinal muscles are variable for understanding LBP and prevention of LBP in the elderly.

Conclusion

We reported the prevalence and related factors of the EILBP. The prevalence of EILBP was 21% and it increased with age. The FIR of the erector spinae at L1-2 and L5-S1 was related to the presence EILBP. The LASD, which is thought as lumbar sagittal balance, did not directly affect the presence of EILBP.

Conflicts of Interest: The authors declare that there are

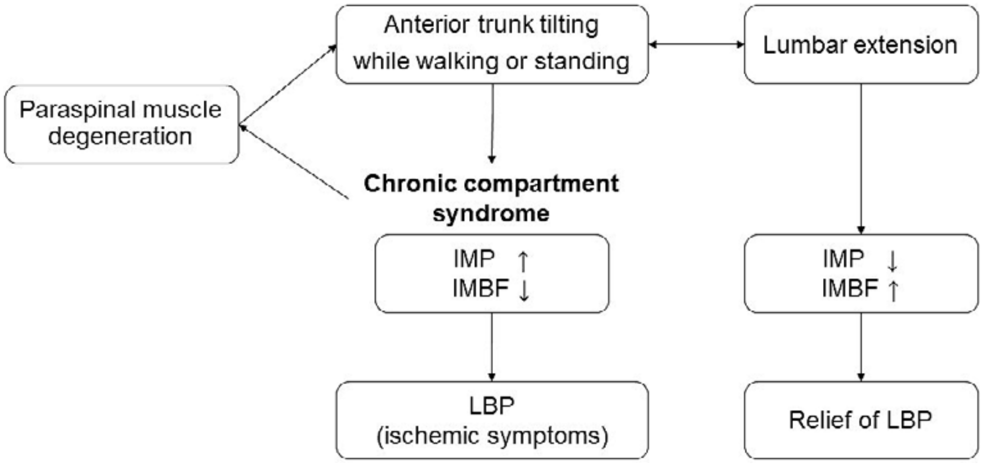

Figure 6. The hypothesis of pathogenesis for EILBP.
Paraspinal muscle degeneration causes anterior trunk tilting posture while walking and standing. It causes chronic compartment syndrome, and chronic compartment syndrome causes LBP. And chronic compartment syndrome can cause further fat degeneration of the paraspinal muscles. In other words, it can lead a vicious cycle.
Abbreviations: EILBP, exercise-induced low back pain; IMP, intramuscular pressure; IMBF, intramuscular blood flow

no relevant conflicts of interest.

Acknowledgement: The authors wish to thank Dr. Akira Onda, Dr. Kazuya Yamauchi, Dr. Yoshiaki Takeyachi, Dr. Ichiro Takahashi, Dr. Hisayoshi Tachihara, and Dr. Bunji Takayama for participating in the data collection. The authors would also like to thank five public nurses (Nobuko Fujita, Nakako Hoshi, Misako Hoshi, Naoko Imada, and Seiko Kanno) for their support in carrying out this study.

This study was supported by a grant from the Fukushima Society for the Promotion of Medicine and a grant from the Fukushima Prefectural Hospitals Office.

Ethical Approval: This study was approved by the ethical committee of Fukushima Medical University (No. 396).

Informed Consent: Informed consent was obtained by all participants in this study.

References

1. Deyo RA, Weinstein JN. Low back pain. N Engl J Med. 2001;344(5):363-70.
2. Fujii T, Matsudaira K. Prevalence of low back pain and factors associated with chronic disabling back pain in Japan. Eur Spine J. 2013;22(2):432-8.
3. Konno S, Kikuchi S, Nagaosa Y. The relationship between intramuscular pressure of the paraspinal muscles and low back pain. Spine. 1994;19(19):2186-9.
4. Takahashi I, Kikuchi S, Sato K, et al. Effects of the mechanical load on forward bending motion of the trunk. Spine. 2007;32(2):E73-8.
5. Nagaosa Y, Kikuchi S, Konno S. Clinical study of intermittent claudication due to low back pain. Orthop Surg Traumatol. 1992;35(6):683-8. Japanese.
6. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Scand. 1989;230:20-4.
7. Bogduk N. Clinical and Radiological Anatomy of the Lumbar spine. 5th ed. London: Churchill Livingston; 2012.
8. Sasaki T, Yoshimura N, Hashizume H, et al. MRI-defined paraspinal muscle morphology in Japanese population: the wakayama spine study. PLOS One. 2017;12(11):e0187765.
9. Otani K, Kikuchi S, Nikaido T, et al. Magnitude of dural tube compression does not show a predictive value for symptomatic lumbar spinal stenosis for 1-year follow-up: a prospective cohort study in the community. Clin Interv Aging. 2018;13:1739-46.
10. Fukuhara S, Bito S, Green J, et al. Translation, adaptation, and validation of the SF-36 Health Survey for use in Japan. J Clin Epidemiol. 1998;51(11):1037-44.
11. Fukuhara S, Ware JE Jr, Kosinski M, et al. Psychometric and clinical tests of validity of the Japanese SF-36 Health Survey. J Clin Epidemiol. 1998;51(11):1045-53.
12. Suzukamo Y, Fukuhara S, Kikuchi S, et al. Validation of the Japanese version of the Roland-Morris Disability Questionnaire. J orthop Sci. 2003;8(4):543-8.
13. Fukuhara S, Suzukamo Y, Bito S, et al. Mannual of SF-36 Japanese version 1.2 Public Health Research Foundation, Tokyo: 2001.
14. Takahashi N, Kikuchi S, Fukuhara S, et al. Estimation of Japanese normative value in age and gender categories of Roland-Morris disability questionnaire. Clinic Orthop Surg. 2004;39(3):315-9. Japanese.
15. Ranson CA, Burnett AF, Kerslake R, et al. An investigation into the use of MR imaging to determine the functional cross sectional area of lumbar paraspinal muscles. Eur Spine J. 2006;15(6):764-73.
16. Kawaguchi Y, Kanamori M, Ishihara H, et al. The association of lumbar disc disease with vitamin-D receptor gene polymorphism. J Bone Joint Surg Am. 2002;84(11):2022-8.
17. Modic MT, Steinberg PM, Ross JS, et al. Degenerative disc disease: assessment of changes in vertebral body marrow with MR imaging. Radiology. 1988;166(1):193-9.
18. Kawakami M, Tamaki T, Ando M, et al. Lumbar sagittal balance

influences the clinical outcome after decompression and posterolateral spinal fusion for degenerative lumbar spondylolisthesis. Spine. 2002;27(1):59-64.

19. Hosmer DW, Lemeshow S, Sturdivant RX. Assessing the fit of the model. *In*: Applied logistic regression. 3rd ed. Hoboken, New Jersey, 153-226, 2013.

20. Youden WJ. Index for rating diagnostic tests. Cancer. 1950;3(1):32-5.

21. Zhu W, Wang W, Kong C, et al. Lumbar muscle fat content has more correlations with living quality than sagittal vertical axis in elderly patients with degenerative lumbar disorders. Clin Interv Aging. 2020;15:1717-26.

22. Danneels LA, Coorevits PL, Cools AM, et al. Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. Eur Spine J. 2002;11(1):13-9.

23. Takemitsu Y, Harada Y, Iwahara T, et al. Lumbar degenerative kyphosis. Clinical, radiological and epidemiological studies. Spine. 1988;13(11):1317-26.

24. Banno T, Arima H, Hasegawa T, et al. The effect of paravertebral muscle on the maintenance of upright posture in patients with adult spinal deformity. Spine deformity. 2019;7(1):125-31.

25. Kim J, Kuno S, Soma R, et al. Relationship between reduction of hip joint and thigh muscle and walking ability in elderly people. Jpn J Phys Fit Sports Med. 2000;49:589-96. Japanese.

26. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. Spine. 1994;19(14):1611-8.

27. Styf J, Lysell E. Chronic compartment syndrome in the erector spinae muscle. Spine. 1987;12(7):680-2.

28. Peck D, Nicholls PJ, Beard C, et al. Are there compartment syndromes in some patients with idiopathic back pain? Spine. 1986;11(5):468-75.

29. Styf J. Pressure in the erector spinae muscle during exercise. Spine. 1987;12(7):675-9.

30. Kobayashi Y, Sekiguchi M, Konno S, et al. Increased intramuscular pressure in lumbar spinal muscles and low back pain. Spine. 2010;35(15):1423-8.

31. Arai I, Kikuchi S, Satou K, et al. Electrophysiological study of exercise-induced low back pain. J Jpn Orthop Assoc. 1995;69(2):s684. Japanese.