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ORIGINAL ARTICLE

Impact of pelvic incidence on lumbar osteophyte formation and disc degeneration in middle-aged and elderly people in a prospective cross-sectional cohort

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Abstract

Purpose Pelvic incidence (PI) is unique to each individual and does not change throughout life. High PI is related to lumbar spondylolisthesis, but associations of PI with lumbar osteophyte formation and disc degeneration are unclear. The objective was to evaluate relationships of PI with lumbar osteophyte formation and disc degeneration, as well as spinal sagittal alignment and geriatric diseases, in middle-aged and elderly people.

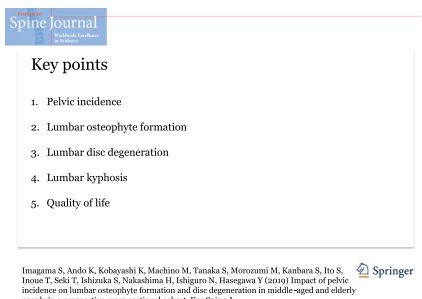
Methods A total of 1002 volunteers (male: 434, female: 568, average age: 63.5) were prospectively examined for lumbar osteophyte formation (Nathan class ≥ 2) and disc degeneration (disc score ≥ 3). High (PI > 51, $n = 501$) and low (PI ≤ 51, $n = 501$) PI groups were defined. Clinical factors, frailty, sarcopenia, and physical quality of life (QOL) were compared between these groups, and risk factors for lumbar osteophyte formation and disc degeneration were identified in multivariate logistic regression analysis.

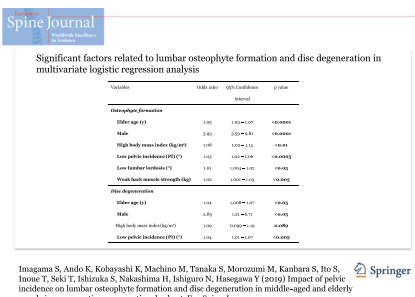
Results Physical QOL was poorer in people with lumbar osteophyte formation (54.8%) and disc degeneration (33.6%). Age, male gender, spinal parameters including PI, bone mineral density, back muscle strength, and gait ability differed significantly between the groups, whereas frailty and sarcopenia were not significantly different. Low PI, low lumbar lordosis, elder age, male gender, high BMI, and weak back muscle strength were significant risk factors for lumbar osteophyte formation and disc degeneration.

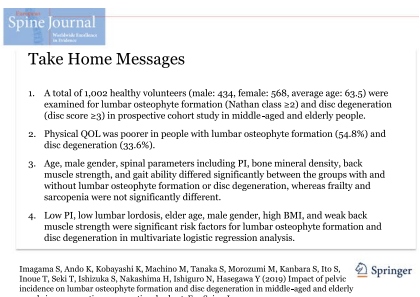
Conclusions Low PI was identified as a risk factor for lumbar osteophyte formation and disc degeneration, both of which reduce physical QOL in middle-aged and elderly people.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







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Keywords Pelvic incidence · Lumbar osteophyte formation · Lumbar disc degeneration · Lumbar kyphosis · Quality of life

Introduction

There has been a recent focus on poor spinal sagittal alignment due to its relationship with outcome after corrective surgery for spinal deformity [1, 2]. Pelvic incidence (PI) is unique to each individual and does not change throughout life [3]. Harmonious lumbar lordosis (LL) with PI is associated with a good surgical outcome [4], and surgical planning that considers PI-LL is common. LL also influences quality of life (QOL) [5], as shown in our previous studies in elderly people in a health check-up [6, 7].

With current ageing of society, there is a need to maintain or improve QOL and activities of daily living (ADL) in elderly people to prolong their healthy lifespan and decrease the cost of nursing care. Orthopaedic degenerative disease can have negative impacts on ADL and QOL in elderly people [8], as well as an increased risk of mortality, in our previous studies [9, 10]. The value of PI is reported as a risk factor for lumbar degenerative change, with a high PI being related to lumbar spondylolisthesis in some studies [11, 12]. Barrey et al. described the associations of spino-pelvic parameters including PI with disc disease and degenerative spondylolisthesis [13]. However, the data were obtained in a retrospective study of only 85 patients with a mean age of 49 years, including 32 with degenerative disc disease, 25 with disc herniation, and 28 with degenerative spondylolisthesis [13]. Therefore, the relationships of PI with lumbar osteophyte formation and disc degeneration are still unclear, particularly with ageing. The objective of this study was to evaluate these relationships, as well as those of PI with spinal sagittal alignment and geriatric disease, in more than 1000 middle-aged and elderly volunteers in a prospective cross-sectional cohort.

Materials and methods

A total of 1002 subjects (male: 434, female: 568, average age: 63.5) who attended a health check-up were prospectively included in the study. This study is part of the "Yakumo study", which is based on an annual health check-up that has been held for over 30 years in Yakumo, Hokkaido, Japan, and is supported by our university and local government [14–17]. Subjects with a surgical history of osteoporotic fractures, those with fresh vertebral fracture and those with scoliosis, were excluded. The study was approved by the Committee on Ethics on Human Research of our University, and informed consent was obtained from all subjects.

Lumbar osteophyte formation, disc degeneration, and spinal sagittal parameters were examined on lateral plain radiographs, as described below. Common geriatric syndromes (frailty and sarcopenia) were also evaluated and were defined as described below. Clinical variables of age, sex, body mass index (BMI), bone mineral density (BMD) expressed in %YAM in the calcaneus, back muscle strength, gait ability determined with the 3-m Timed Up and Go (3-m TUG) test, and physical QOL using the physical component summary (PCS) in SF-36 (Japanese version 2.0) were examined in statistical analysis.

Radiographic evaluation

Osteophyte formation, disc degeneration, PI, thoracic kyphosis angle (T1-12), lumbar lordosis angle (L1-S1), sacral slope, and pelvic tilt (PT) were measured on a digitalized lumbar lateral standing radiograph. The ratio of the thoracic kyphosis and lumbar lordosis angles (T/L ratio) firstly defined by Jackson et al. [18, 19] was calculated to evaluate stooped posture, as reported in our previous study [7, 20, 21]. A large T/L ratio indicates a more bent forward posture. A positive lumbar lordosis angle indicates lordosis in this study.

Osteophyte formation was evaluated using the Nathan classification (0–4) for L1/2–L5/S1 [22], as reported in our previous study [23], with positive osteophyte formation defined as class 2 in this study. Disc degeneration was evaluated using the decrease in disc height in four segments at L2/3, 3/4, 4/5, and 5/S1, using the disc score defined by Miyakoshi et al. [24, 25] The disc ratio was calculated as disc height divided by disc height at L1/2 for each segment, and each disc score was defined as 2, 1, and 0 for disc ratios of ≤ 0.5, 0.5 to 0.8, and ≥ 0.8, respectively. The total disc score was calculated as the sum of these four values (0 is best, and 8 is worst), and disc degeneration was defined as a total disc score ≥ 4 (Fig. 1).

Common geriatric syndromes (frailty and sarcopenia)

Frailty and sarcopenia in elderly people are areas of current interest. In this study, these conditions were examined as possible risk factors for lumbar osteophyte formation and disc degeneration. Frailty was originally proposed by Fried et al. [26]. In the current study, we used the modified criteria for frailty defined in the Japanese version of the Cardiovascular Health Study [J-CHS] [27]. Thus, frailty was diagnosed if subjects had ≥ 3 of 5 criteria: unintentional weight loss (> 2 kg in the past 6 months without

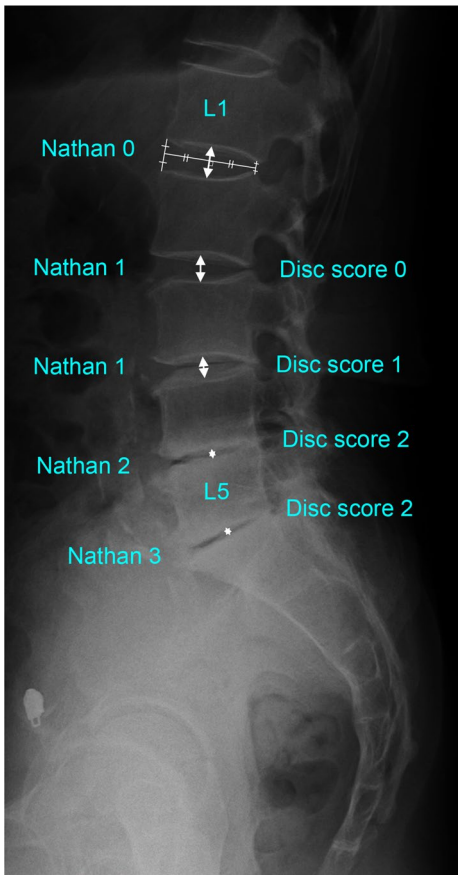

Fig. 1 Evaluation of osteophyte formation and disc degeneration. The Nathan classification (0–3) for L1/2–L5/S1 is shown in this case, which defined osteophyte formation + (Nathan classification ≥ 2). The disc ratio was calculated as disc height divided by disc height at L1/2 for each L2/3, 3/4, 4/5, 5/S1 segment, and total disc score was 5 (0 + 1+2 + 2) in this case, which defined disc degeneration + (a total disc score ≥ 4)

any particular cause), weakness (decrease in grip strength based on Asian Working Group for Sarcopenia [AWGS] criteria [28]: grip strength < 26 kg in males and < 18 kg in females), low walking speed (usual gait speed < 1.0 m/s), self-reported exhaustion, and self-reported low physical activity.

For sarcopenia, bioelectrical impedance analysis (BIA) (Inbody 720; Biospace Co., Ltd., Seoul, Republic of Korea) was used to measure appendicular skeletal muscle mass [29]. The BIA reference values for diagnosis of muscle loss are an appendicular skeletal muscle index of < 7.0 kg/m^2 in men and < 5.8 kg/m^2 in women [30, 31]. Sarcopenia in the healthy volunteers in this study was simply defined as a decrease in muscle mass, without inclusion of gait speed or grip strength in the definition.

Statistical analysis

The mean PI of 51.0 was used to divide the subjects into high (PI ≥ 51, $n = 501$) and low (PI < 51, $n = 501$) PI groups. The average PI is 47.7–52.3 [32, 33], and Roussouly et al. used PI ≥ 51 as the high PI type in sagittal classification [34], which is consistent with our findings. PI and clinical variables of age, sex, BMI, %YAM, back muscle strength, 3-m TUG, frailty, sarcopenia, and PCS in SF-36 were compared between the high and low PI groups by unpaired t test and Chi-squared test. Risk factors for lumbar osteophyte formation and disc degeneration were identified in multivariate logistic regression analysis with an odds ratio (OR). $p < 0.05$ was considered to be significant in all analyses. Lastly, PI was divided into six classes according to Barrey's classification [13] to evaluate the relationship of the detailed PI classification and lumbar degenerative change. There were only four subjects in class VI, and therefore, statistical analysis was conducted in five groups (I, II, III, IV, and V + VI) by Tukey–Kramer test. All statistical analyses were performed with SPSS ver.22 (SPSS Inc., Chicago, IL, USA).

Results

The characteristics of the 1002 subjects are given in Table 1, and the high and low PI groups are compared in Table 2. Age did not differ significantly between these groups, but there were a significantly higher percentage of males, and a significantly flatter spinal sagittal alignment (smaller thoracic kyphosis angle, lumbar lordosis angle, PT, and sacral slope with a slight bent forward posture) in the low PI group. Subjects with low PI also had significantly higher rates of lumbar osteophyte formation and disc degeneration ($p < 0.0001$, Fig. 2a, b).

Subjects with lumbar osteophyte formation were significantly older and more frequently male and had higher BMI, lower PI, smaller lumbar lordosis angle and sacral slope with a larger thoracic kyphosis angle and a bent forward posture, lower back muscle strength, and slower gait speed (Table 3). %YAM did not differ significantly between subjects with and without lumbar osteophyte formation. Disc degeneration was significantly associated with an older age, male gender, higher BMI, lower PI, lower PT, larger T/L ratio, and lower back muscle strength (Table 4). %YAM was significantly related to disc degeneration, but there was no difference in gait ability in subjects with and without disc degeneration. There were no significant differences in the rates of frailty and sarcopenia in subjects with and without lumbar osteophyte formation and disc degeneration, but both lumbar osteophyte formation and disc degeneration had a significantly negative impact on physical QOL (Tables 3, 4).

Table 1 Characteristics of the 1002 subjects

Variable	Value
Age (years)	63.5 (10.3)
Gender (male, %) (*n*)	43.3% (*n* = 434)
Body mass index (kg/m^2)	23.5 (3.3)
Spinal parameters	
Pelvic incidence (PI) (°)	51.1 (9.5)
Thoracic kyphosis angle (°)	39.7 (9.5)
Lumbar lordosis angle (°)	42.1 (12.4)
Sacral slope (°)	31.4 (10.4)
Pelvic tilt (PT) (°)	19.7 (12.0)
Thoracic/lumbar (T/L) ratio	1.04 (0.60)
%YAM	80.7% (15.2)
Back muscle strength (kg)	73.2 (30.0)
3-m TUG (s)	6.4 (1.1)
Geriatric disease	
Frailty (%) (*n*)	9.9% (*n* = 99)
Sarcopenia (%) (*n*)	14.7% (*n* = 147)
Quality of life	
PCS (SF-36)	49.4 (11.1)

Values are shown as a mean or percentage (SD or number of patients (*n*) in parentheses)

Positive value indicates lordosis of the lumbar spine in this study

YAM young adult mean, *TUG* Timed Up and Go test, *PCS* physical component summary

In multivariate logistic regression analysis, high age, male gender, high BMI, low PI, low lumbar lordosis, and weak back muscle strength were significant risk factors for lumbar osteophyte formation (Table 5); high age, male gender, and low PI were significant risk factors and high BMI showed a tendency to be a risk factor for lumbar disc degeneration (Table 5).

To examine the impact of PI on lumbar degenerative disease in detail, PI was divided into six classes according to Barrey et al. (Table 6). Both osteophyte formation and disc degeneration gradually increased with lowering of PI. Significant differences between low PI and high PI were found for the prevalences of lumbar degenerative diseases (Table 7).

Discussion

PI of the elderly people was not influenced by age, but a low PI had a significant impact on flatter changes in the thoracic spine, lumbar spine, and sacral inclination, as well as a bent forward posture in this study. Therefore, subjects with low PI may easily proceed to poor spinal sagittal alignment beyond compensation mechanism with ageing. Previous reports have shown relationships of PI with lumbar spondylolisthesis and lumbar facet joint degeneration [11, 12, 35–37], and of PI with lumbar disc diseases and lumbar degenerative spondylolisthesis in a small case series by Barrey et al. Therefore, this is the first study to evaluate the relationships of lumbar osteophyte formation and lumbar disc degeneration with PI, as well as with muscle strength, physical ability, frailty, and sarcopenia, in a large number of middle-aged and elderly volunteers. The results of this prospective cohort study support the conclusion of Barrey et al. that patients with disc lesions are characterized by a normal or low PI with a straight spine. Musculoskeletal

Table 2 Comparison of parameters in subjects with low and high pelvic incidence (PI)

Variables	Low PI (*n* = 501)	High PI (*n* = 501)	*p* value
Age (years)	63.1 (10.8)	63.8 (9.7)	NS
Gender (male, %) (*n*)	51.3% (*n* = 257)	35.3% (*n* = 177)	**< 0.0001**
Body mass index (kg/m^2)	23.5 (3.5)	23.6 (3.2)	NS
Spinal parameters			
Pelvic incidence (PI) (°)	43.4 (5.3)	58.8 (6.0)	**< 0.0001**
Thoracic kyphosis angle (°)	39.0 (9.5)	41.7 (9.1)	**< 0.05**
Lumbar lordosis angle (°)	38.0 (11.4)	46.2 (12.0)	**< 0.0001**
Sacral slope (°)	29.3 (10.6)	33.5 (9.8)	**< 0.0001**
Pelvic tilt (PT) (°)	14.1 (11.3)	25.2 (9.9)	**< 0.0001**
Thoracic/lumbar (T/L) ratio	1.1 (0.37)	0.98 (0.77)	**< 0.05**
%YAM	81.3 (14.4)	80.1 (15.9)	NS
Quality of life			
PCS (SF-36)	49.9 (11.0)	48.9 (11.2)	NS

Bold values indicate the statistically significant factors

Values are shown as a mean or percentage (SD or number of patients (*n*) in parentheses)

Positive value indicates lordosis of the lumbar spine in this study

YAM young adult mean, *PCS* physical component summary, *NS* not significant

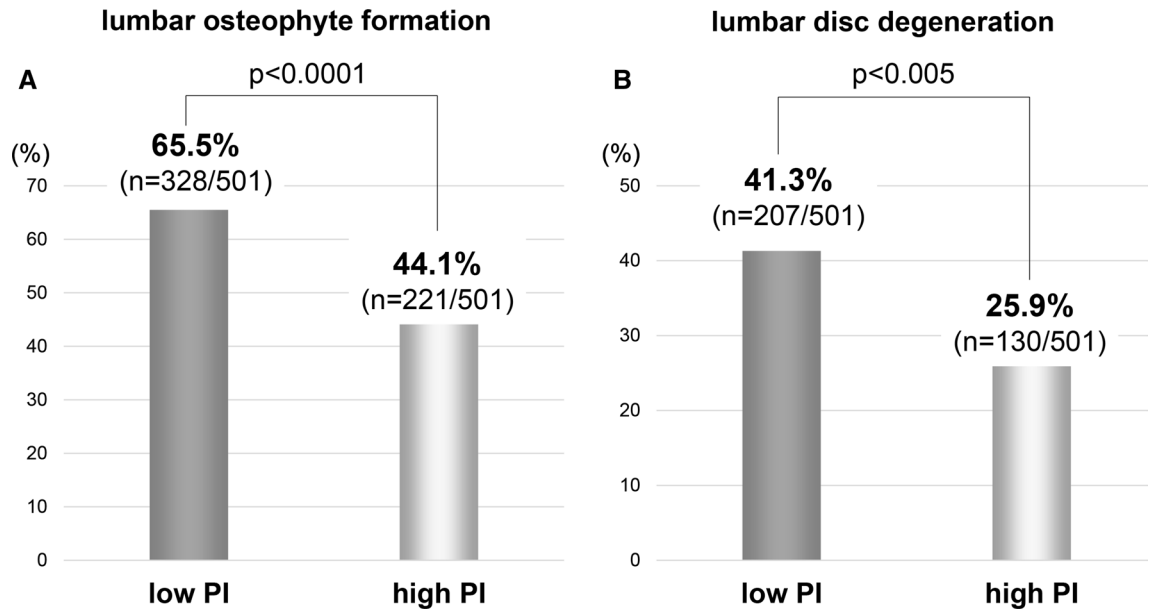

Fig. 2 Rate of lumbar osteophyte formation and disc degeneration in the low and high PI groups. Subjects with low PI had significantly higher rates of lumbar osteophyte formation (**a**, $p < 0.0001$) and disc degeneration (**b**, $p < 0.005$)

Table 3 Comparison of parameters in subjects with and without lumbar osteophyte formation

Variables	Osteophyte formation (+) ($n = 549$)	Osteophyte formation (−) ($n = 453$)	p value
Age (years)	65.8 (9.7)	60.7 (10.3)	**< 0.0001**
Gender (male, %) (*n*)	60.1% ($n = 330$)	23.0% ($n = 104$)	**< 0.0001**
Body mass index (kg/m^2)	24.0 (3.3)	22.9 (3.4)	**< 0.0001**
Spinal parameters			
Pelvic incidence (PI) (°)	49.2 (8.9)	53.4 (9.7)	**< 0.0001**
Thoracic kyphosis angle (°)	40.4 (9.6)	38.8 (9.8)	**< 0.05**
Lumbar lordosis angle (°)	39.2 (12.2)	45.6 (11.6)	**< 0.0001**
Sacral slope (°)	29.5 (10.4)	33.7 (10.0)	**< 0.0001**
Pelvic tilt (PT) (°)	19.7 (12.4)	19.7 (11.5)	NS
Thoracic/lumbar (T/L) ratio	1.2 (0.75)	0.91 (0.33)	**< 0.0001**
%YAM	81.3 (14.6)	80.0 (15.8)	NS
Back muscle strength (kg)	67.0 (28.4)	78.5 (30.4)	**< 0.0001**
3-m TUG (s)	6.5 (1.1)	6.3 (1.0)	**< 0.05**
Geriatric disease			
Frailty (%) (*n*)	9.7% ($n = 73$)	10.1% ($n = 46$)	NS
Sarcopenia (%) (*n*)	13.3% ($n = 73$)	16.3% ($n = 74$)	NS
Quality of life			
PCS (SF-36)	48.4 (11.4)	50.7 (10.7)	**< 0.001**

Bold values indicate the statistically significant factors

Values are shown as a mean or percentage (SD or number of patients (*n*) in parentheses)

Positive value indicates lordosis of the lumbar spine in this study

YAM young adult mean, *TUG* Timed Up and Go test, *PCS* physical component summary, *NS* not significant

degenerative disease is common in elderly people and influences their ADL and QOL [8]. Therefore, prevention of this disease may contribute to improvement of QOL. In fact, this study showed that both lumbar osteophyte formation and lumbar disc degeneration had a significant impact on poor physical QOL. Thus, improvement of QOL in elderly people

Table 4 Comparison of parameters in subjects with and without lumbar disc degeneration

Variables	Disc degeneration (+) ($n=337$)	Disc degeneration (−) ($n=665$)	p value
Age (years)	63.9 (10.0)	61.7 (10.8)	**< 0.005**
Gender (male, %) (*n*)	55.5% ($n=187$)	37.1% ($n=247$)	**< 0.05**
Body mass index (kg/m^2)	26.1 (2.4)	23.4 (3.7)	**< 0.05**
Spinal parameters			
Pelvic incidence (PI) (°)	49.6 (8.8)	53.7 (10.0)	**< 0.001**
Thoracic kyphosis angle (°)	40.3 (8.6)	39.1 (9.4)	NS
Lumbar lordosis angle (°)	43.6 (11.8)	43.9 (11.1)	NS
Sacral slope (°)	28.7 (8.9)	30.7 (9.2)	NS
Pelvic tilt (PT) (°)	20.9 (12.1)	23.0 (11.8)	NS
Thoracic/lumbar (T/L) ratio	1.2 (1.1)	1.0 (0.36)	**< 0.05**
%YAM	79.4 (16.8)	84.4 (12.4)	**< 0.005**
Back muscle strength (kg)	65.4 (28.3)	72.6 (29.2)	**< 0.05**
3-m TUG (s)	6.4 (1.2)	6.4 (0.93)	NS
Geriatric disease			
Frailty (%) (*n*)	8.0% ($n=27$)	10.8% ($n=72$)	NS
Sarcopenia (%) (*n*)	12.5% ($n=42$)	15.8% ($n=105$)	NS
Quality of life			
PCS (SF-36)	49.0 (8.8)	51.5 (9.9)	**< 0.05**

Bold values indicate the statistically significant factors

Values are shown as a mean or percentage (SD or number of patients (*n*) in parentheses)

Positive value indicates lordosis of the lumbar spine in this study

YAM young adult mean, *TUG* Timed Up and Go test, *PCS* physical component summary, *NS* not significant

Table 5 Significant factors related to lumbar osteophyte formation and disc degeneration in multivariate logistic regression analysis

Variables	Odds ratio	95% Confidence interval	p value
Osteophyte formation			
Elder age (year)	1.05	1.03–1.07	**< 0.0001**
Male	5.93	3.59–9.81	**< 0.0001**
High body mass index (kg/m^2)	1.08	1.02–1.14	**< 0.01**
Low pelvic incidence (PI) (°)	1.03	1.02–1.06	**< 0.0005**
Low lumbar lordosis (°)	1.01	1.004–1.02	**< 0.05**
Weak back muscle strength (kg)	1.02	1.001–1.03	**< 0.005**
Disc degeneration			
Elder age (year)	1.04	1.008–1.07	**< 0.05**
Male	2.85	1.21–6.71	**< 0.05**
High body mass index (kg/m^2)	1.09	0.099–1.19	***0.089***
Low pelvic incidence (PI) (°)	1.04	1.01–1.07	**< 0.005**

Bold values indicate the statistically significant factors

Only significant factors are shown

The p value of high BMI in bolditalic showed a tendency to be a risk factor for lumbar disc degeneration

may require preventive interventions for lumbar osteophyte formation and disc degeneration.

In multivariate logistic regression analysis, six independent risk factors for lumbar osteophyte formation and four for lumbar disc degeneration were identified. These factors may be essential targets for preventive interventions for improvement of QOL. Ageing is unavoidable, but males with a low PI have a particular risk of lumbar osteophyte formation and disc degeneration without an influence of ageing because male gender and PI were risk factors independent of age. Regarding PI and lumbar spine degeneration, the risk factor for lumbar facet joint degeneration is recently reported as high PI [35, 36] and high PI with lumbar hyperlordosis [37]. Conversely, the subjects with low lumbar lordosis and low PI bear the load of lumbar spine by anterior and middle elements rather than posterior, which may partly proceed lumbar osteophyte formation and lumbar disc degeneration. Roussouly et al. reported that stress in a flat lordosis (classification of lumbar lordosis: type 2) is at its maximum on discs with a high risk of early disc herniation, and thus, low PI and low lumbar lordosis may be the worst combination for lumbar disc degeneration. A male with low PI and low lumbar lordosis has an even greater risk of lumbar osteophyte formation. Therefore, males with low PI should take care to avoid a load on the lumbar spine, such as that caused by bending forward or lifting heavy items, and should

Table 6 Comparison of spinal parameters and the rates of lumbar osteophyte formation and disc degeneration among six PI classes [13]

Variables	Barrey's classification					
	I (PI < 38°) (*n* = 79)	II (38° ≤ PI < 48°) (*n* = 325)	III (48° ≤ PI < 58°) (*n* = 367)	IV (58° ≤ PI < 68°) (*n* = 180)	V (68° ≤ PI < 78°) (*n* = 47)	VI (PI ≥ 78°) (*n* = 4)
Spinal parameters						
Pelvic incidence (PI) (°)	34.2 (3.5)	43.9 (2.8)	53.1 (2.7)	61.6 (2.7)	71.0 (2.4)	78.7 (0.9)
Pelvic tilt (PT) (°)	7.1 (11.3)	14.7 (10.3)	21.1 (10.7)	28.9 (8.5)	30.9 (8.3)	37.3 (5.5)
Sacral slope (°)	27.1 (10.5)	29.2 (10.1)	32.0 (10.4)	32.7 (8.6)	40.1 (8.4)	41.4 (3.7)
Lumbar lordosis angle (°)	36.7 (11.1)	38.2 (11.7)	42.9 (12.1)	46.2 (11.6)	54.4 (9.2)	54.5 (5.2)
Thoracic kyphosis angle (°)	38.4 (11.4)	38.4 (9.6)	41.1 (8.6)	39.9 (9.3)	39.7 (11.5)	44.0 (8.4)
Lumbar degeneration						
Osteophyte formation (%) (*n*)	67.1% (*n* = 53)	64.0% (*n* = 208)	55.0% (*n* = 202)	39.4% (*n* = 71)	31.9% (*n* = 15)	0% (*n* = 0)
Disc degeneration (%) (*n*)	43.0% (*n* = 34)	39.4% (*n* = 128)	30.7% (*n* = 113)	19.4% (*n* = 35)	14.9% (*n* = 7)	0% (*n* = 0)

Values are shown as a mean or percentage (SD or number of patients (*n*) in parentheses)

Positive value indicates lordosis of the lumbar spine in this study

Table 7 Statistical differences in the rates of lumbar osteophyte formation and disc degeneration in Barrey's classification of PI

Variables	Barrey's classification				
	I (PI < 38°) (*n* = 79)	II (38° ≤ PI < 48°) (*n* = 325)	III (48° ≤ PI < 58°) (*n* = 367)	IV (58° ≤ PI < 68°) (*n* = 180)	V + VI (PI ≥ 68°) (*n* = 51)
Osteophyte formation					
I	NS	**< 0.05**	**< 0.0001**	**< 0.001**	
II		**< 0.05**	**< 0.0001**	**< 0.0005**	
III			**< 0.0005**	**< 0.01**	
IV				**< 0.05**	
V + VI					
Disc degeneration					
I	NS	NS	**< 0.05**	**< 0.05**	
II		NS	**< 0.01**	**< 0.005**	
III			**< 0.005**	**< 0.01**	
IV				NS	
V + VI					

Bold values indicate the statistically significant factors

NS not significant

also try to improve other risk factors. Considering the two-group comparison in this study, spinal parameters have a direct impact on lumbar osteophyte formation and lumbar disc degeneration. Therefore, the most important intervention may be to maintain or improve spinal sagittal alignment with range of motion and muscle exercises, and stretching intervention as previously reported [38–40]. Daily habits of lumbar range of motion, stretching, and muscle exercises in middle-aged and elderly people may contribute to prevention of lumbar degeneration and low back pain [6]. However, the pathology and optimal intervention are still unclear, and further biomechanical research and an interventional cohort study are needed.

High BMI was found to be an independent risk factor for osteophyte formation and disc degeneration, which is likely to be due to the heavier load placed on the lumbar spine. In addition, a recent study showed the negative impact of obesity on the ability to compensate for sagittal malalignment through pelvic retroversion [41, 42], which suggests that obesity can easily lead to spinal malalignment with insufficient lower extremity compensation mechanism. In this respect, obesity may have a negative impact on lumbar

osteophyte formation and disc degeneration as well as spinal sagittal alignment.

Weak back muscle strength may lead to lumbar osteophyte formation. Strong back muscle strength contributes to maintenance of lumbar lordosis and spinal alignment, and to better QOL in previous studies [5–7]. Therefore, back muscle strengthening exercise will contribute to prevention of osteophytes and reduction of lumbar lordosis, which is another risk factor for osteophyte formation. However, too extensive back muscle strengthening exercise may also accelerate lumbar degeneration by repeated heavy loading, and so mild exercise may be more effective [6, 43], especially for elderly people. A prospective interventional study is needed to evaluate the efficacy of these preventive methods. In comparison between groups, gait ability and BMD, as well as age, male gender, BMI, spinal parameters, and back muscle strength, were found to be significant factors associated with these events. Gait ability also had a significant relationship with lumbar osteophyte formation, which raises the possibility that strengthening exercise for lower leg muscles and walking exercise in elderly people may contribute to prevention of osteophytes by decreasing mechanical stress on the spine due to strengthened muscles. However, this is speculative and requires confirmation in a future study. Low BMD is also related to lumbar disc degeneration in this study. Obviously, as this study does not include severe osteoporotic subjects with vertebral fractures, different mechanical stress to intervertebral disc may occur in osteoporotic vertebra. However, alendronate has favourable effects on disc degeneration with osteoporosis in the past report [44]. The relationship and pathology between osteoporosis and intervertebral disc degeneration are still unclear, but some recent basic researches have reported that osteoporosis and osteochondral remodelling of the endplate caused intervertebral disc degeneration in ovariectomized mice [45], and that oestrogen deficiency exacerbated intervertebral disc degeneration; then, oestrogen supplementation alleviated the progression of disc degeneration [46].

There are some limitations in the study. First, the subjects in the health check-up were relatively healthy volunteers who worked in agriculture or fishing, which differs from an urban population. This may explain why frailty and sarcopenia had no significant relationship with lumbar osteophyte formation and disc degeneration. Second, we have shown that nutrition and blood test data such as serum antioxidant levels also have an impact on lumbar osteophyte formation [23], and these factors need to be further examined in a future study. Third, magnetic resonance imaging (MRI) could not be performed to define disc degeneration. It is difficult to conduct MRI in a health check-up for more than one thousand subjects, but disc degeneration on MRI may differ among all PI classes based on the rate of disc degeneration in Table 7. Lastly, a recent study showed that facet joint degeneration or ageing of the lumbar spine mainly occurs in the lower lumbar spine [36], which suggests that results for osteophyte formation and disc degeneration and their influence on spinal sagittal alignment may differ for each lumbar segment. However, the results of this study are valuable in firstly establishing relationships of lumbar osteophyte formation and disc degeneration with PI, and with muscle strength, physical ability, and geriatric diseases. A further study is needed to determine more details of ageing of the lumbar spine.

In conclusion, PI in 1002 elderly volunteers was related to spinal sagittal alignment, and both lumbar osteophyte formation and disc degeneration had a negative impact on physical QOL. Low PI was identified as a risk factor for both of these conditions, along with low lumbar lordosis, male gender, high BMI, and weak back muscle strength in middle-aged and elderly people.

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Compliance with ethical standards

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