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Spinopelvic Alignment as a Risk Factor for Poor Balance Function in Low Back Pain Patients

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Abstract

Study Design: Retrospective, observational study.

Objectives: This study aimed to examine the association between spinopelvic parameters and balance function in low back pain (LBP).

Methods: Among patients in the rehabilitation medicine department, the data of 182 patients (mean age, 47.8 years; M/F = 64/118) was obtained retrospectively. Spinopelvic parameters were measured through a whole-body low-dose biplanar radiography using the EOS imaging system, and balance function was evaluated by the center of pressure (COP) movement using the Zebris treadmill system. Pearson correlations were used to determine the relationship between radiographic and balance function. Stepwise multiple linear regression analyses were conducted with the balance function as a dependent variable and age and spinopelvic parameters as independent variables.

Results: Increased age, knee flexion (KF), pelvic tilt (PT), C7-central sacral line (C7-CSL) and C7 sagittal vertical axis (SVA), and decreased spino-sacral angle (SSA) were associated with both poor static and dynamic balance. Moreover, increased Cobb's angle and decreased thoracic kyphosis (TK) and lumbar lordosis (LL) was associated with poor static balance. Increased pelvic incidence (PI) was related to poor dynamic balance. Increased age, Cobb's angle, SVA, and decreased TK were risk factors for poor static balance. For dynamic balance, increased age, C7-CSL, and PT were risk factors for poor sagittal balance, whereas increased CAM-plumb line and PT were risk factors for poor coronal balance.

Conclusions: Balance function was associated with spinopelvic parameters in patients with LBP. Increased SVA, followed by increased PT, was the strongest independent factor associated with poor static and dynamic balance.

Keywords

low back pain, spine, pelvis, postural balance

Introduction

Balance is a multidimensional concept that refers to the ability of a person to not fall.[1] Various objective tools have been developed for balance assessment, including posturography, wearable inertial sensor, and force platform.[2,3] Among these tools, the center of pressure (COP) recorded from a force platform is considered the gold standard measure of balance and generally used as the index of balance parameter. The Zebris treadmill (FDM-T system, Zebris Medical GmbH, Germany) is a force platform-embedded treadmill, which can

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measure COP movement and balance performance with high validity and reliability.[4-6]

Balance is important because decreased balance function may induce a fear of falling, which can reduce the quality of life and limit the ability to complete daily activities.[7] To maintain balance, complex integration, and coordination of multiple systems, such as the vestibular, proprioceptive, visual, and musculoskeletal systems, is required.[8,9] Any deficit in these systems can lead to balance impairment, and patients with low back pain (LBP) also show impaired balance, poor postural control, and experience frequent falls. In patients with LBP, decreased lumbar spine mobility, impaired proprioception, decline in lumbar extension strength, and abnormal posture have been suggested as the possible factors for decline in balance.[10-13]

Moreover, spinopelvic alignment was reported to be an important factor in maintaining a balanced posture.[10,14] Spinopelvic alignment refers to the relationship between the morphology and orientation of the pelvis to that of the vertebral spine and line of gravity. Low-dose biplanar radiographic scan of the whole body using EOS (EOS® imaging, Paris, France) is a widely adopted method to assess spinopelvic alignment, with demonstrated accuracy, reliability, and repeatability.[15,16]

Patients with LBP have specific pattern of spinopelvic alignment, including low sacral slope (SS), low lumbar lordosis (LL), and small pelvic incidence (PI).[10,17,18] In a previous study on patients with LBP, thoracic kyphosis (TK) and loss of LL seemed to contribute to greater postural instability.[19] In other studies, LL improved patients' balance strategy, and a significant correlation between lordosis and COP displacement was observed.[20,21] Despite evidence indicating that spinopelvic alignment exerts important influence on balance control, currently, information on the relationship between spinopelvic alignment and balance in patients with LBP is still lacking.

This study aimed to investigate the relationships between coronal and sagittal spinopelvic alignment and static and dynamic postural balance in patients with back pain using EOS and the Zebris treadmill.

Materials and Methods

Participants

This retrospective study was approved by the institutional review board of our hospital (approval number: 3-2021-0311). Radiographic and balance data of 182 patients who visited the tertiary hospital from July 2018 to July 2021 because of back pain were reviewed. The inclusion criteria were (i) presence of LBP for at least the past 6 months; (ii) underwent EOS and used the Zebris treadmill; and (iii) age ≥18 years. The exclusion criteria were (i) inability to stand alone; (ii) inability to walk 5 m independently; and (iii) presence of neurodegenerative disease.

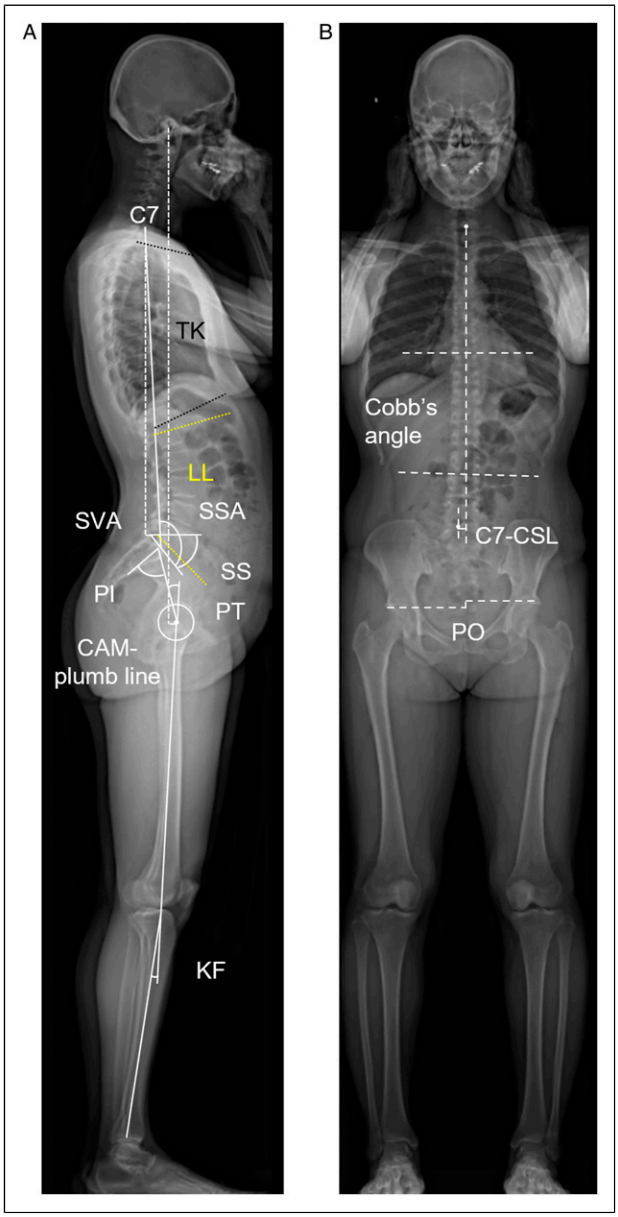

Figure 1. Measurements of spinopelvic parameters: **(A)** sagittal plane and **(B)** the coronal plane. TK, thoracic kyphosis; LL, lumbar lordosis; SSA, spino-sacral angle; SVA, C7 sagittal vertical axis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt; CAM-plumb line, center of acoustic meatus point–plumb line; KF, knee flexion; C7-CSL, C7-central sacral line; and PO, pelvic obliquity.

Spinopelvic Alignment Assessment With EOS

Participants underwent a low-dose biplanar radiographic scan of the whole body with EOS. The scan was performed in the upright posture, with both the arms raised and the fingertips placed on the cheek bones. All images were acquired and processed by trained radiographers with more than 2 years of experience using EOS technology. In the sagittal plane,

parameters, including the center of acoustic meatus point–plumb line (CAM-plumb line), knee flexion (KF), LL, PI, pelvic tilt (PT), SS, spino-sacral angle (SSA), C7 sagittal vertical axis (SVA), and TK, were analyzed. In the coronal plane, parameters, including C7-central sacral line (C7-CSL), Cobb's angle, and pelvic obliquity (PO), were measured. A CAM-plumb line was recorded as the horizontal distance between the center of the femoral heads and the vertical line traversing the center of the auditory canals. KF was defined as the angle between the mechanical femoral axis and the mechanical tibial axis. LL was measured from the superior endplate of L1 and inferior endplate of L5. PI was defined as the angle between a line perpendicular to the sacral plate at its midpoint and a line connecting this point to the femoral head axis. PT was defined as the angle between the vertical and line through the midpoint of the sacral plate to the femoral head axis. SS was defined as the angle between the line toward the superior endplate of S1 and horizontal plane. SSA was measured as the angle between a line from the center of C7 to the center of the sacral endplate and sacral endplate itself. SVA was recorded as the horizontal distance between the posterior edge of the sacral plate and vertical line traversing the center of the C7 vertebra. TK was measured from the superior endplate of T1 and inferior endplate of T12. C7-CSL was recorded as the horizontal distance between the midpoint of the C7 vertebral body and the midline of the sacrum. Cobb's angle of the major curve was also measured. PO was recorded as the distance between the highest point of each acetabulum (Figure 1A and B).

Balance Assessment With Zebris Treadmill

Balance was evaluated using the Zebris treadmill. An electronic mat of force sensors is embedded underneath the treadmill belt; therefore, the force exerted by a participant's feet can be recorded. First, to assess static balance, participants stood on the treadmill for 10 s, and pressure distribution beneath their feet was recorded. As the pressure shifted, the postural sway path of COP was analyzed, and the following parameters were acquired (Figure 2A):

(1) Sway path length of COP (COP length) (mm), defined as the total length of the path marked by COP.
(2) Average velocity of COP (COP velocity) (mm/s), defined as the mean velocity at which the COP moves; this parameter indicates the speed of changes in the COP location, reflecting the speed of postural reactions while standing.
(3) Area of ellipse (COP area) (mm^2), defined as the size of the area marked by COP; the ellipse area includes 95% of the COP measurement points.

After the measurement of static balance, participants were instructed to walk on the treadmill to assess dynamic balance. Participants started at a speed of .5 km/h, and the belt speed was increased by .3 km/h every 15 s in a stepwise manner until the participants informed the tester of the speed that best characterized their normal walking motion. Each participant was instructed to walk barefoot on the treadmill for 1 consecutive minute at their comfort speed, and the following set of parameters was automatically derived from the continuous trace of the COP trajectory (Fig. 2B):

(1) Anterior/posterior variability (COP AP) (mm), defined as the standard deviation of the intersection point in the anterior/posterior direction; a value of "zero" is equivalent to constant strides while walking on the treadmill.
(2) Lateral asymmetry (COP lateral) (mm): left/right shift of the intersection point; zero position is equivalent to perfect symmetry.

Statistical Analysis

Statistical analysis was performed using IBM SPSS statistics software version 25.0 (IBM, Armonk, NY, USA). Parameters

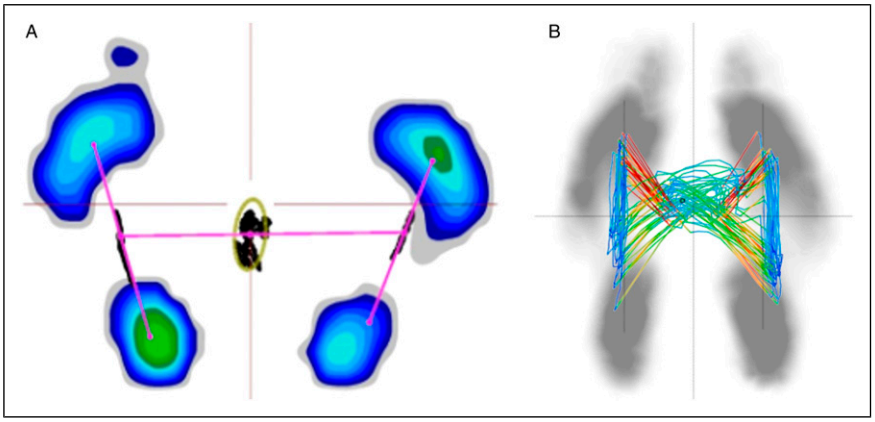

Figure 2. Balance measurement presentation: **(A)** center of pressure (COP) trajectory presentation for static balance measurement and **(B)** cyclogram reflecting the movement of COP during ambulation on a treadmill for dynamic balance measurement.

are described using the basic measurement of descriptive statistics (mean, standard deviation [SD]). A Pearson's correlation analysis was used to examine the relationship between the spinopelvic and balance parameters. Stepwise multiple linear regression analyses were conducted using balance data acquired from the Zebris treadmill as the dependent variable and age and spinopelvic parameters measured using EOS as the independent variables. A *P*-value <.05 was considered statistically significant.

Results

Patient Demographic Data and Spinopelvic Parameters

A total 182 patients with LBP were included in this study. The mean age was 47.8 years, and men comprised 35.2% of the study population (n = 64). The major diagnosis of participants based on radiographic and physical examinations varied from degenerative scoliosis, disc herniation, non-specific LBP, spinal stenosis, and spondylolisthesis to spondylosis (Table 1). Moreover, the radiographic sagittal and coronal parameters of patients are summarized in Table 1.

Correlation Between Age, Spinopelvic Parameters Measured by EOS, and Balance Function Measured by the Zebris Treadmill

Results from the correlation analysis are presented in Table 2. Age, KF, PT, C7-CSL, SVA, and SSA showed a correlation with both static and dynamic balance. Age showed a positive correlation with COP area (r = .156, *P* = .04), length (r = .252, *P* < .01), velocity (r = .256, *P* < .01), AP (r = .264, *P* < .01), and lateral asymmetry (r = .278, P <.01). KF also showed a positive correlation with COP area (r = .190, *P* = .01), length (r = .159, *P* = .03), velocity (r = .158, *P* = .03), AP (r = .202, *P* < .01), and lateral (r = .207, *P* < .01). PT showed a positive correlation with COP length (r = .197, *P* < .01), velocity (r = .198, *P* < .01), AP (r = .318, *P* < .01), and lateral (r = .315, *P* < .01). C7-CSL showed a positive correlation with COP AP (r = .315, *P* < .01). SVA showed a positive correlation with COP area (r = .212, *P* < .01), length (r = .400, *P* < .01), velocity (r = .401, *P* < .01), AP (r = .253, *P* < .01), and lateral (r = .261, *P* < .01). SSA showed a negative correlation with COP area (r = −.170, *P* = .02), length (r = −.254, *P* < .01), velocity (r = −.253, *P* < .01), and lateral (r = −.188, *P* = .01). Cobb's angle, TK, and LL showed a correlation only with static balance. Cobb's angle showed a positive correlation with COP area (r = .238, *P* < .01). TK showed a negative correlation with COP length (r = −.313, *P* < .01) and velocity (r = −.317, *P* < .01). LL showed a negative correlation with COP length (r = −.319, *P* < .01) and velocity (r = −.320, *P* < .01). PI showed a positive correlation with only dynamic balance, including COP AP (r = .221, *P* < .01) and lateral (r = .149, *P* < .01).

Table 1. Participant characteristics.

Variable	
Age (mean, SD)	47.8 (16.6)
Sex, male (%)	64 (35.2)
Diagnosis, N (%)	
Degenerative scoliosis	15 (8.2)
Disc herniation	53 (29.1)
Non-specific low back pain	22 (12.1)
Spinal stenosis	48 (26.4)
Spondylolisthesis	18 (9.9)
Spondylosis	26 (14.3)
Spinopelvic parameter	
Sagittal plane	
CAM-plumb line (mm)	−15.4 (36.7)
KF (°)	2.0 (5.8)
LL (°)	35.5 (13.7)
PI (°)	49.9 (10.8)
PT (°)	13.6 (8.8)
SS (°)	36.3 (9.3)
SSA (°)	127.6 (10.4)
SVA (mm)	2.5 (34.1)
TK (°)	38.1 (11.5)
Coronal plane	
C7-CSL (mm)	10.6 (9.5)
Cobb's angle (°)	7.7 (6.3)
PO (mm)	3.9 (3.8)

SD, standard deviation; N, number; CAM-plumb line, center of acoustic meatus point–plumb line;KF, knee flexion; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SSA, spino-sacral angle; SVA, C7 sagittal vertical axis; TK, thoracic kyphosis;C7-CSL, vertical length between C7 vertebra and central sacral line; and PO, pelvic obliquity.

Multiple Linear Regression Analysis for Balance Function

Results from the multiple linear regression analysis that predicted balance are presented in Table 3. Cobb's angle (*P* = .001) and SVA (*P* = .002) were predictors of the COP area. SVA (*P* < .001) and TK (*P* < .001) were predictors of COP length. SVA (*P* < .001), TK (*P* < .001), and age (*P* < .001) were predictors of COP velocity. PT (*P* = .003), C7-CSL (*P* < .001), and age (*P* = .049) were predictors of COP AP, and PT (*P* < .001) and CAM-plumb line (*P* = .001) were predictors of COP lateral.

Discussion

The results of this study suggest that, in patients with LBP, the contributing factor to balance is different in static and dynamic conditions. Increased SVA was the most important factor contributing to poor static balance. In case of dynamic balance, increased C7-CSL was the most important contributing factor for poor dynamic sagittal balance, while increased PT was the most important risk factor for poor dynamic coronal balance. Increased age was a contributing factor to both poor static and dynamic balance.

Table 2. Correlation among age, spinopelvic parameter, and balance parameter.

	Static Balance			Dynamic Balance	
Correlation (r)	COP area	COP length	COP velocity	COP AP	COP lateral
Age	**.156***	**.252***	**.256****	**.264****	**.278****
Spinopelvic parameter					
Sagittal					
CAM-plumb line	**.171***	**.223****	**.224****	.101	**.204***
KF	**.190***	**.159***	**.158***	**.202****	**.207****
LL	−.100	**−.319****	**−.320****	−.113	−.089
PI	.027	.098	.099	**.221****	**.149***
PT	.115	**.197****	**.198****	**.318****	**.315****
SS	−.077	−.074	−.074	−.041	−.120
SSA	**−.170***	**−.254****	**−.253****	−.142	**−.188***
SVA	**.212****	**.400****	**.401****	**.253****	**.261****
TK	−.084	**−.313****	**−.317****	.028	−.002
Coronal					
C7-CSL	.140	**.158***	**.157***	**.315****	.136
Cobb's angle	**.238****	.086	.085	.049	−.046
PO	.094	.065	.068	.058	.074

CAM-plumb line, center of acoustic meatus point–plumb line; KF, knee flexion; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SSA, spino-sacral angle; SVA, C7 sagittal vertical axis; TK, thoracic kyphosis; C7-CSL, vertical length between C7 vertebra and central sacral line; and PO, pelvic obliquity. *, $P < .05$; **, $P < .01$.

Table 3. Multilinear regression analysis with a stepwise condition.

Dependent Variable		Independent Variable	B	β	t	*P*	VIF	R	R^2	Adjusted R^2	D-W
Static balance	COP area	Constant	98.74		5.64	<.01		.33	.11	.10	1.80
		SVA	1.03	.22	3.14	<.01	1.00				
		Cobb's angle	6.15	.25	3.50	<.01	1.00				
	COP length	Constant	228.49		10.62	<.01		.47	.22	.21	2.00
		SVA	.97	.36	5.29	<.01	1.03				
		TK	−2.00	−.25	−3.70	<.01	1.03				
	COP velocity	Constant	19.77		7.46	<.01		.49	.24	.23	2.03
		Age	.08	.15	2.00	.04	1.31				
		SVA	.08	.28	3.71	<.01	1.35				
		TK	−.22	−.28	−4.10	<.01	1.07				
Dynamic balance	COP AP	Constant	1.77		1.11	.27		.44	.19	.18	1.88
		Age	.07	.15	1.99	.04	1.17				
		PT	.19	.22	2.99	<.01	1.18				
		C7-CSL	.20	.26	3.73	<.01	1.04				
	COP lateral	Constant	2.24		2.61	.01		.39	.15	.14	2.12
		CAM-plumb line	.04	.23	3.25	<.01	1.00				
		PT	.25	.33	4.77	<.01	1.00				

B, unstandardized coefficients; β, standardized coefficients; VIF, variance inflation factor; D-W, Durbin-Watson SVA, C7 sagittal vertical axis; TK, thoracic kyphosis; PT, pelvic tilt; C7-CSL, vertical length between C7 vertebra and central sacral line; and CAM-plumb line, center of acoustic meatus point–plumb line.

Aging causes alterations in the neuromuscular system and decreases physiological functions, which in turn can lead to muscle weakness, sensory-motor deficits, and consequent altered trunk muscle activity.[22] These changes can induce impaired balance, and several studies have demonstrated that older adults show increased postural sway.[23-25] In this study, we verified that age-related deterioration in both static and dynamic balance function also occurs in patients with LBP.

In case of static balance, increased SVA was the most important factor for poor static balance. SVA is the distance between the sacral plate and the center of the C7 vertebra, and it has been proposed as the main parameter for evaluating

global sagittal balance.[26,27] In previous studies, increased SVA has been shown to be related to a higher prevalence of sarcopenia and paraspinal muscle degeneration, compromising the quality of life and independence of patients, and increasing the risk of falls.[28-31] Subjects with increased SVA commonly show a posterior shifting of the sacrum and increased PT, which is a compensatory mechanism to maintain the standing balance.[32] In patients with LBP, the decrement of pelvic movement can often be observed due to a reduction in relative motion between the pelvis and also because of weakened abdominal muscles.[33,34] Decreased pelvic movement may lead to the loss of compensatory motion of the pelvis to maintain balance, consequently making it more difficult for patients with LBP to maintain balance against increased SVA.

The risk factor for poor dynamic balance differs according to the sagittal and coronal direction. COP Lateral, which demonstrates the movement of the center in the coronal direction, was influenced by an anatomical sagittal imbalance, including PT and CAM-plumb line. However, COP AP, which represents the sagittal movement of COP, was influenced by anatomical coronal imbalance, including C7-CSL. It is assumed that during dynamic performance, including walking, the presence of coronal imbalance increases anterior-posterior movements to compensate the imbalance, and that the presence of sagittal imbalance increases left-right movements.

The position of the pelvis can be influenced by many factors, such as LL, muscle tightness, and habitual posture.[35] Increased PT is known to be correlated with pelvic retroversion in walking and with decreased pelvic mobility during gait. Trunk movement in the medio-lateral direction seems to increase to maintain balance.[36] Contrary to static balance, the CAM-plumb line, which is the global sagittal imbalance, including cervical alignment and cranial position, was more important than SVA in determining the extent of medio-lateral trunk movement. Nevertheless, C7-CSL is the parameter that shows the relationship between the cervical spine and sacrum placement. C7-CSL is widely used to evaluate trunk coronal imbalance, and it can be influenced by several factors, such as spinal curvature, leg length discrepancy, and PO.[37]

This study has several limitations. First, due to the lack of information about actual fall events, it was not possible to confirm whether the increase in COP was directly associated with clinically impactful imbalance. However, a systemic review and meta-analysis has already established that several COP displacement parameters are good indices to discriminate fallers from non-fallers.[38] Therefore, increased COP sway can be interpreted as a meaningful clinical imbalance. Moreover, use of a treadmill to measure dynamic balance parameters can raise concerns that the participant's normal, non-artificial walking pattern may have been affected. Nevertheless, we assumed that the influence would have been minimized because COP was measured while walking at the speed at which the participant felt most comfortable. Another important limitation is the diverse underlying pathophysiology of the patients with LBP in this study. The participants' diagnosis varied from spinal stenosis, disc herniation, and spondylosis to non-specific LBP; however, pain intensity, which can also affect balance function, was not evaluated in this study. This factor makes it difficult to interpret the results of this study, and further studies are needed to investigate whether there is a difference in the spinopelvic parameter that contributes to postural imbalance in each disease. Further examination in subsequent studies will likely enhance our understanding of this matter.

This study is meaningful because it identified the risk factor for balance deterioration in patients with LBP. Despite the fact that some previous researchers have investigated balance function and related factors in patients with LBP, this is the first study to analyze the relationship between spinopelvic alignment and balance function. Based on this study, we can devise balance improving exercise focused at decreasing positive sagittal imbalance and coronal imbalance in patients with LBP.

Conclusions

This study demonstrated that spinopelvic parameters and balance function were significantly associated in patients with LBP. Forward-deviated spinal alignment was the strongest risk factor for poor static balance. A posteriorly tilted pelvis was the strongest risk factor for poor dynamic balance. Interestingly, in dynamic balance, the radiographic coronal imbalance was the risk factor for poor sagittal dynamic balance, whereas the radiographic sagittal imbalance was the risk factor for poor coronal dynamic balance.

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Authors' Contribution

Substantial contributions to the conception or design of the work: Eunsil Cha and Jung Hyun Park. Acquisition, analysis, or interpretation of data: Eunsil Cha. Drafting work for important intellectual content: Eunsil Cha and Jung Hyun Park. Critical review and final approval of the version to be published: Jung Hyun Park

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethics Approval

This retrospective study was approved by the institutional review board (3-2021-0311). The study protocol was conducted according to the principles of the Declaration of Helsinki.

Informed consent

Informed consent was waived from Institutional Review Board because this retrospective study complies with standard practice and does not expose patient-identifiable information.

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