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Original Article

Relationship between degenerative scoliosis and lower extremity mechanical parameters based on EOS imaging system

Bo Zhang[1*], Yi-Ning Gong[1*], Xiang-Cheng Gao[1*], Yong-Gang Tang[2], Ding-Jun Hao[1], Bao-Rong He[1], Ze-Chao Qu[1], Liang Yan[1]

Departments of [1]Spine Surgery, [2]Radiology, Honghui Hospital, Xi'an Jiaotong University, Xi'an, Shaanxi, China. [*]Equal contributors.

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Abstract: Objective: This study aimed to assess the correlation between coronal imbalance and lower-limb physiological parameters in degenerative scoliosis using the biplanar whole body imaging system (EOS). Materials and methods: A total of 101 successive EOS images were selected between January 2018 and December 2021. Of the selected images, 63 patients were in the degenerative scoliosis group (DSG) and 38 patients were in the control group (CG). Two independent observers performed measurements of the parameters and compared the two groups. Results: Among parameters examined, significant inter-group differences were found for coronal pelvic tilt angle (CPT), bilateral femoral length difference (ΔFL), and bilateral total lower limb length (ΔTL) difference. Additionally, the knee and ankle joints had more severe degeneration on the main curved side in patients with degenerative scoliosis. In the left curved group, 18 (42.86%) and 24 (57.1%) patients had more severe degeneration in the left knee and left ankle, respectively. In the right lateral bending group, 13 (61.9%) and 14 (66.7%) patients had more severe degeneration in the right knee and right ankle, respectively. Statistical differences were found in the degree of degeneration in both knee and ankle joints bilaterally. Conclusion: This study showed that biomechanical parameters of the lower limbs are affected in cases of degenerative scoliosis with altered coronal balance. The lower limb on the main curve side became shorter compared to its counterpart, and joint degeneration of the knee and ankle joints became more severe.

Keywords: Degenerative scoliosis, biplanar whole body imaging system (EOS), coronal balance, biomechanical parameter, lower limb

Introduction

Adult degenerative scoliosis (ADS) is a subset of adult scoliosis defined by a coronal Cobb angle greater than 10° [1]. Because the lumbar and thoracolumbar segments are usually involved, this is also commonly referred to as degenerative lumbar scoliosis (DLS) [2]. The prevalence of ADS is reported to be 7.5-36% [3, 4]. Many studies have shown that in patients with spinal deformities, maintaining a horizontal gaze and upright posture often requires recruitment of compensatory mechanisms in the spine, pelvis, and lower limbs [5, 6]. Lafage et al. [7] suggested that changes in the knee and ankle positions may play a role in maintaining a gravity line relationship with the foot, and an analysis from head to toe is required. It is worthwhile to consider whether coronal imbalance in patients with degenerative scoliosis affects irregular forces in the lower limbs, leading to altered physiological parameters in the lower limbs.

Although conventional magnetic resonance imaging (MRI) and computed tomography (CT) equipment can be used, the equipment available in most clinical settings is not suitable for performing imaging in patients in the upright position, as the bone in a state of stress is necessary to study biomechanical equilibrium. The biplanar whole body imaging system (EOS) is based on ultrasensitive X-ray detection technology, allowing simultaneous whole-body anteroposterior (AP) and lateral images in a calibrated environment for osteoarticular diseases, especially spinal deformities [8]. The advantages of EOS imaging include true-to-size images rather than the single-source divergent X-ray beams of conventional radiology, thus avoiding measurement errors due to X-ray beam distortion. EOS radiographs have been found to have good intra-observer and inter-observer repeatability [9]. Additionally, the EOS system is sufficiently accurate for radiological measurements [10]. The EOS system also provides a full-body view, making it possible to assess global spinal balance and its relationship with the pelvis and lower limbs.

Usually, surgeons consider sagittal imbalance of the spine as a key parameter for orthopedics, while the functional impact of coronal imbalance of the spine is underestimated. More importantly, the relationship between coronal imbalance and degeneration of the lower extremity joints is less studied and is still being measured by conventional X-ray imaging and MRI. These imaging techniques do not allow us to understand the relationship between the coronal imbalance of the spine and the lower extremity parameters from the true skeletal stress state [11, 12]. This study aimed to use the EOS 2D imaging method to investigate whether lower limb parameters are altered in patients with degenerative scoliosis compared to the normal population, and to investigate whether there is an effect on lower limb biomechanical parameters in patients with coronal imbalance. Finally, we compared lateral differences in knee and ankle degeneration in patients with degenerative scoliosis.

Materials and methods

Patient selection

The study participants were all individuals scanned by EOS between January 2018 and December 2021 in Xi'an Honghui Hospital. The study was approved by the institutional review board of Honghui Hospital (No. 202206006), and the need for informed consent was waived owing to the retrospective nature of the study and the absence of any intervention. The inclusion criteria were as follows: (1) degenerative scoliosis (defined as a Cobb angle greater than 10° due to degeneration) or normal participants; (2) scanned in 2D under EOS with anterior-posterior and lateral images; (3) standard camera posture (patients were asked to take a weight bearing position, arms flexed at 45 degrees with their fingers on their clavicles and patella and toes facing forward); and (4) age no less than 45 years. The exclusion criteria were as follows: (1) patients with spinal diseases such as spinal fractures, infections, tumors, rheumatoid arthritis, and compulsory spondylitis; (2) concurrent neuromuscular disease; (3) a history of spinal and lower limb surgery; (4) congenital malformation of the lower limb; and (5) unclear radiographic images.

Radiographic measurements

Six spinal parameters (sagittal vertical axis [SVA], thoracic kyphosis angle [TK], thoracolumbar kyphosis angle [TLK], lumbar lordosis angle [LL], spino-sacral angle [SSA], sacral slope angle [SS], and cobb angle), six spinopelvic parameters (T1 spinopelvic inclination angle [T1SPI], T9 spinopelvic inclination angle [T9SPI], pelvic incidence angle [PI], pelvic tilt angle [PT], coronal vertical axis [CVA], coronal pelvic tilt angle [CPT]), and eight lower limb parameters (hip-knee-ankle angle [HKAA], medial proximal femoral angle [MPFA], mechanic lateral distal femoral angle [mLDFA], medial proximal tibia angle [MPTA], lateral distal tibia angle [LDTA], total skeletal lower limb length, femoral length, tibial length) were measured in the full-body anteroposterior and lateral views (**Table 1**; **Figure 1**).

Intra- and inter-observer reliabilities of observers in EOS 2D (EOS Imaging, France) were assessed using intraclass correlation coefficients. Two observers (doctors trained and experienced in using the software) completed the measurements on 20 randomly selected cases twice over 7 days. Assessments were performed using the criteria set by Winer, with 0-0.24 as weak, 0.25-0.49 as low, 0.50-0.69 as moderate, 0.70-0.89 as good, and 0.9-1 as excellent.

To check for any directional differences between the lower limb parameters, we subtracted the results of the contralateral limb from the results of the main curved side in the degenerative scoliosis group and the results of the right limb from the results of the left limb in the control group. The difference is expressed as "Δ". Thus, not only the absolute value, but also its directionality, is obtained according to the results.

Table 1. Measurement of spinal, spinopelvic and lower limb parameters

SVA	The distance between the C7 plumb line and the posterosuperior aspect of S1 [33].
TK	The angle between the upper endplate of T_4 and the lower endplate of T_{12} [34].
TLK	The angle between the upper endplate of T_{11} and the lower endplate of L_2 [34].
LL	The angle between the upper endplate of L1 and S1 [34].
SSA	The angle between a line delimited by the central point of the C7 vertebral body and the central point of the S1 sacral plateau and a second line, which is the sacral slope line [35].
SS	The angle between the horizontal line and upper endplate of S1 [33].
T1SPI	The angle is formed by the vertical reference line and the line between the center of the T1 vertebral body and the bicoxofemoral axis [6].
T9SPI	The angle is formed by the vertical reference line and the line between the center of the T-9 vertebral body and the center of the bicoxofemoral axis [6].
PI	The angle between the line through the center of the femoral head and the midpoint of the sacral plate and the line perpendicular to the sacral plate [33].
PT	The angle between the line drawn through the center of the femoral head and the midpoint of the sacral plate and the vertical reference [33].
Cobb Angle	On X-rays, the vertebra with the greatest inclination on the cephalic and caudal sides of the spinal curve is called the Cobb angle end vertebrae. A straight line is drawn along the upper end plate of the upper end vertebrae and the lower end plate of the lower end vertebrae. The angle between the two lines or the intersection of their perpendicular lines is the Cobb angle [36].
CVA	The distance between the vertical distance and coronal C7 plumb line and the central perpendicular line of the sacrum [37].
CPT	The pelvic obliquity was measured as the angle between the horizontal reference line and the line connecting the uppermost borders of both iliac crests [38].
HKAA	The lateral angle between the mechanical axis of the femur and the tibia [33].
MPFA	The angle was measured between the femoral shaft axis and the line joining the center of the femoral head to the superior greater trochanter [39].
mLDFA	The angle is the lateral angle between the distal femur articular surface and the mechanical axis of the femur [40].
MPTA	The medial angle between the mechanical axis of the tibia and proximal tibia joint line [33].
LDTA	The angle between the tibial mechanical axis and distal tibial joint surface [33].
Total skeletal lower limb length	The distance from the top of the femoral head to the midpoint of the tibial plafond [41].
Femoral length	The distance from the top of the femoral head to the midpoint of the tangent line between the medial and lateral femoral condyles [41].
Tibial length	The distance from the middle of the tibial intercondylar eminence to the midpoint of the tibial plafond [41].

SVA: sagittal vertical axis; TK: thoracic kyphosis angle; TLK: thoracolumbar kyphosis angle; LL: lumbar lordosis angle; SSA: spino-sacral angle; SS: sacral slope angle; T1SPI: T1 spinopelvic inclination angle; T9SPI: T9 spinopelvic inclination angle; PI: pelvic incidence angle; PT: pelvic tilt angle; CVA: coronal vertical axis; CPT: coronal pelvic tilt angle; HKAA: hip-knee-ankle angle; MPFA: medial proximal femoral angle; mLDFA: mechanical lateral distal femoral angle; MPTA: medial proximal tibial angle; LDTA: lateral distal tibial angle.

Figure 1. Parameter measurements. The patient was 65 years old, the side of main curve was towards the left. Lines A, B and C represent total lower limb length, femur length and tibia length, respectively.

Table 2. Intra- and inter-rater reliability test for all radiographic parameters

Parameter	Intra-rater coefficient	Inter-rater coefficient
SVA	0.97	0.95
TK	0.97	0.94
TLK	0.93	0.93
LL	0.96	0.96
SSA	0.94	0.93
SS	0.95	0.91
T1SPI	0.92	0.91
T9SPI	0.94	0.91
PI	0.92	0.91
PT	0.93	0.91
CVA	0.97	0.94
CPT	0.89	0.89
HKAA (Left)	0.95	0.93
HKAA (Right)	0.95	0.94
MPFA (Left)	0.90	0.93
MPFA (Right)	0.93	0.92
mLDFA (Left)	0.88	0.88
mLDFA (Right)	0.83	0.83
MPTA (Left)	0.92	0.86
MPTA (Right)	0.92	0.86
LDTA (Left)	0.84	0.87
LDTA (Right)	0.84	0.83
Total length (Left)	0.95	0.81
Total length (Right)	0.96	0.94
Femoral length (Left)	0.92	0.91
Femoral length (Right)	0.94	0.94
Tibal length (Left)	0.96	0.92
Tibal length (Right)	0.95	0.91
KL Classification (Left)	0.88	0.82
KL Classification (Right)	0.80	0.82
Takakura Classification (Left)	0.80	0.80
Takakura Classification (Right)	0.81	0.87

SVA: sagittal vertical axis; TK: thoracic kyphosis angle; TLK: thoracolumbar kyphosis angle; LL: lumbar lordosis angle; SSA: spino-sacral angle; SS: sacral slope angle; T1SPI: T1 spinopelvic inclination angle; T9SPI: T9 spinopelvic inclination angle; PI: pelvic incidence angle; PT: pelvic tilt angle; CVA: coronal vertical axis; CPT: coronal pelvic tilt angle; HKAA: hip-knee-ankle angle; MPFA: medial proximal femoral angle; mLDFA: mechanical lateral distal femoral angle; MPTA: medial proximal tibial angle; LDTA: lateral distal tibial angle.

Grading for the degeneration of the knee and ankle joints

Based on the bilateral knee and ankle joints in the anteroposterior radiograph, we chose the severe side for both the degenerative scoliosis and control groups for comparison.

Kellgren-Lawrence grading: Kellgren-Lawrence (KL) grading classifies osteoarthritis into the following five grades: KL0, normal; KL1, mild osteochondrosis; KL2, definite osteochondrosis; KL3, narrowing of the joint space with large osteochondrosis; and KL4, osteosclerosis and narrowing of the joint space with large osteochondrosis [13].

Takakura grading: In Takakura grading, ankle osteoarthritis is divided into four stages: stage 1, early sclerosis and bone formation without joint space narrowing; stage 2, narrowing of the medial joint space; stage 3a, occlusion of the medial joint space; stage 3b, advancement of the joint space occlusion to the top of the talus; and stage 4, complete contact between the joint space occlusion and full contact with the bone [14]. Based on this, we used stage 0 to represent the normal ankle joint.

Statistical analysis

IBM SPSS (IBM Corp., Armonk, NY, USA), version 23, was used for statistical analysis. The normality of the data was tested using the Kolmogorov-Smirnov test. Age between the degenerative scoliosis and control groups were tested using the independent samples t-test, sex differences were tested using the chi-square test, and differences in parameters between the groups were tested using the Mann-Whitney test. Comparisons within the degenerative scoliosis group were performed using the Wilcoxon test. In all cases, a value of $P < 0.05$ to was considered significant for our results.

Results

A total of 101 study participants, 38 men and 63 women, aged 45-84 years (mean 64±9.6 years) met the inclusion criteria. There were 63 individuals in the degenerative scoliosis group (DSG) and 38 in the control group (CG). The mean Cobb angle in the DSG was 19.63±9.47°. There were no statistically significant differences in the male-to-female ratio (P=0.058) or age (P=0.115) between the two groups.

Intra- and inter-observer reliability assessments for all parameters gave values above 0.8 and were considered "good" or "excellent" (**Table 2**). When comparing the sagittal param-

Table 3. Radiographic spinal parameters in the degenerative scoliosis and control groups

Parameter	DSG	CG	*P*-value
Age	65.5	61.2	0.115
Sex			0.058
Male	19 (37.6%)	19 (50%)	
Female	44 (62.4%)	19 (50%)	
SVA	35.5±5.2 mm	24.1±5.4 mm	0.131
TK	28.8±1.9°	33.7±1.9°	0.031*
TLK	12.4±1.2°	11.8±1.3°	0.912
LL	26.0±1.8°	39.2±2.4°	<0.001**
SSA	121.7±1.5°	128.8±1.7°	0.004**
SS	32.2±10.0°	36.9±11.3°	0.091

SVA: sagittal vertical axis; TK: thoracic kyphosis angle; TLK: thoracolumbar kyphosis angle; LL: lumbar lordosis angle; SSA: spino-sacral angle; SS: sacral slope angle; DSG: the degenerative scoliosis group; CG: the control group. *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

Table 4. Sagittal spinal and spinopelvic parameters in the degenerative scoliosis and control groups

Parameter	DSG	CG	*P*-value
T1SPI	4.3±0.4°	3.5±0.4°	0.337
T9SPI	9.2±0.7°	8.4±0.8°	0.565
PI	53.22±14.52°	52.63±2.0°	0.835
PT	20.0±1.5°	15.6±1.4°	0.09
CVA	18.2±2.0 mm	10.9±1.4 mm	0.029*
CPT	2.7±0.2°	1.7±0.2°	0.001**

T1SPI: T1 spinopelvic inclination; T9SPI: T9 spinopelvic inclination; PI: pelvic incidence; PT: pelvic tilt; CVA: coronal vertical axis; CPT: coronal pelvic tilt; DSG: the degenerative scoliosis group; CG: the control group. *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

eters of the spine between the DSG and CG, we found that the mean values of TK (28.8±1.9° vs 33.7±1.9°, P=0.031), LL (26.0±1.8° vs 39.2±2.4°, P < 0.001), and SSA (121.7±1.5° vs 128.8±1.7°, P=0.004) were significantly smaller in the DSG than in the CG. There were no significant differences in any other sagittal parameters between the two groups (**Table 3**).

We further compared spinopelvic parameters between the DSG and CG. There were no significant differences in T1SPI, T9SPI, PI, or PT between the two groups. CVA was significantly higher in the DSG (18.2±2.0 mm) than in the CG (10.9±1.4 mm) (P=0.029). In addition, the coronal pelvis tilt angle was significantly higher in DSG than CG (2.7±0.2° vs 1.7±0.2°, P=0.001) (**Table 4**).

No significant differences were found in the ΔHKAA, ΔMPFA, ΔLDFA, ΔMPTA, or ΔLDTA angles when comparing the lower limb parameters. However, a significant discrepancy in ΔTL was found between the two groups (-3.0±1.1 mm vs 0.2±0.9 mm, P=0.017). There was a statistically significant difference in ΔFL (-1.7±0.8 mm vs 0.8±0.5 mm, P=0.014), but no significant difference in bilateral tibia length (ΔTiL) (-0.7±0.5 mm vs -0.2±0.6 mm, P=0.325) (**Table 5**).

A comparison between the groups showed that knee (2.9±0.8 vs 2.3±0.9, P=0.001) and ankle (1.8±0.6 vs 1.1±0.5, P < 0.001) degeneration severity was higher in DSG than in CG with a statistically significant difference (**Table 6**). To further analyze whether there were lateral differences in knee and ankle degeneration, the degenerative scoliosis group was divided into two groups according to the direction of the main curved sides for comparison of the knee and ankle joints.

The results of the comparison of the knee and ankle joints in the main curved side direction were summarized (**Table 7**). The results revealed that in the group in which the main curved side is toward left and right, there is a statistically significant difference in the grading of knee degeneration between the left and right sides (left 2.9±0.8 vs right 2.6±0.7, P= 0.023; left 2.3±0.5 vs right 2.8±0.8, P=0.04), respectively, and the degeneration of the knee joint in the direction of the main curved side was more severe. Similar trends in the grading of ankle degeneration were found. In the group in which the main curved side was toward left and right, a statistically significant difference was found in the comparison of bilateral ankle degeneration (left 1.6±0.5 vs right 1.1±0.7, P < 0.001; left 1.0±0.6 vs right 1.8±0.7, P=0.002), and the degeneration of the ankle joint in the direction of the main curved side was more severe, respectively (**Figure 2**).

Discussion

Studies have shown that patients with degenerative spine disease need to achieve balance by increasing the overall sway in multiple planes compared with healthy controls [15, 16]. Our

Table 5. Lower limb radiographic parameters in the degenerative scoliosis and control groups

Characteristics	DSG	CG	*P*-value
ΔHKAA	1.8±2.8°	-1.37±0.7°	0.746
ΔMPFA	1.6±1.6°	-0.1±0.4°	0.901
ΔLDFA	0.1±0.3°	0.5±0.3°	0.162
ΔMPTA	0.1±0.4°	-0.03±0.4°	0.939
ΔLDTA	-0.4±0.4°	-0.3±0.3°	0.425
ΔTotal skeletal lower limb length	-3.0±1.1 mm	0.2±0.9 mm	0.017*
ΔFemoral length	-1.7±0.8 mm	0.8±0.5 mm	0.014*
ΔTibal length	-0.7±0.5 mm	-0.2±0.6 mm	0.325

HKAA: hip-knee-ankle angle; MPFA: medial proximal femoral angle; LDFA: mechanic lateral distal femoral angle; MPTA: medial proximal tibia angle; LDTA: lateral distal tibia angle; DSG: the degenerative scoliosis group; CG: the control group. Degenerative scoliosis group: using the main curve side subtracted from the opposite side. Control group: using the difference between the left lower limb subtracted from the right lower limb. *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

Table 6. Distribution of severity of degeneration in the knee and ankle joints in the degenerative scoliosis and control groups

Classification		DSG	CG	*P*-Value
KL Classification	0	0	0	0.001**
	1	0	5 (13.2%)	
	2	23 (36.5%)	21 (55.3%)	
	3	23 (36.5%)	5 (13.2%)	
	4	17 (27%)	7 (18.3%)	
Takakura Classification	0	0	3 (7.9%)	P<0.001**
	1	18 (28.6%)	30 (78.9%)	
	2	40 (63.5)	4 (10.5%)	
	3	5 (7.9%)	1 (2.7%)	
	4	0	0	

DSG: the degenerative scoliosis group; CG: the control group. *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

findings support our hypothesis that disruption of the biomechanical balance in degenerative scoliosis affects the anatomical parameters of the lower extremities. We found significant differences in ΔFL, ΔTL, and the degree of knee and ankle degeneration between the DSG and CG. In addition, we found significant differences in the degree of bilateral knee and ankle degeneration in the DSG depending on the direction of the main curved side.

Recently, many studies have found a close association between sagittal sequence imbalance and the lower limbs in patients with scoliosis [17-19]. Yasuda et al. [20] found that poor lumbopelvic alignment in the sagittal position, particularly posterior pelvic tilt, may contribute to the progression of knee osteoarthritis. We compared the sagittal spinal and spinopelvic parameters between the DSG and CG and found that TK and LL values were reduced in patients with degenerative scoliosis. This is consistent with previous studies that showed that patients with degenerative lumbar spondylolisthesis and lumbar disc herniation could be characterized by a flat spine with significantly reduced lumbar lordosis and thoracic kyphosis [21]. Anterior imbalance is often directly secondary to loss of lumbar lordosis. Simultaneously, other changes in spinopelvic parameters may occur (e.g., reduced thoracic kyphosis may limit the forward shift of the center of gravity), corresponding to a compensatory mechanism [5]. SSA values usually correlate strongly with the sacral slope angle in a balanced spine. In a sagittal compensatory effect, the pelvis tilts posteriorly, bringing the upper endplate of the S1 closer to the axis of the femur and increasing the sacrofemoral distance to compensate for the forward shift of the center of gravity [22]. This compensatory mechanism may have led to a reduction in SSA in the degenerative scoliosis group.

Previous studies have shown that PI as a morphological parameter of the pelvis remains stable in adulthood [23, 24]. Considering that PI=PT+SS, the pelvis tilts more at high PI than at low PI, thus allowing for a greater range of adaptation [25, 26]. Although no statistically significant difference in PT values between the degenerative and control groups was found in our study, we still observed a trend toward a significant increase in PT values in patients with degenerative scoliosis. Our study found significant differences in coronal pelvic tilt angle between the degenerative scoliosis and

Table 7. Summary of comparative knee and ankle degeneration in the major curved side

n	Side of main curve	Left knee/ankle joint with more severe degeneration	No difference between the two sides	Right knee/ankle joint with more severe degeneration
Knee	Left	18 (42.86%)	18 (42.86%)	6 (14.28%)
	Right	4 (19%)	4 (19%)	13 (62%)
Ankle	Left	24 (57.1%)	13 (31%)	5 (11.9%)
	Right	2 (9.5%)	5 (23.8%)	14 (66.7%)

Values are presented as the number of patients (%).

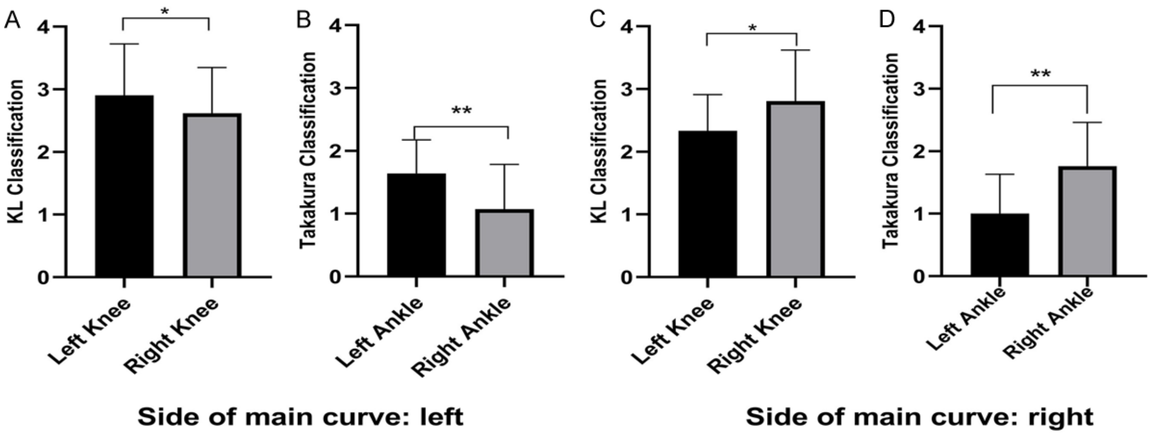

Figure 2. Significant differences were observed in the degree of degeneration in the knee and ankle joints of both lower extremities depending on the direction of the main bending side. The degeneration degree of both knee and ankle is higher in the main curved side than in the contralateral side. *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

control groups. Previous studies have shown that scoliosis and increased coronal pelvic coronal tilt are closely associated with spasticity and deformity of the knee joint [27]. Yagi et al. [28] found a significant difference in weight loading between the right and left feet of adult patients with scoliosis through force platform analysis, and this difference was significantly reduced after orthopedic surgery. Patients with degenerative scoliosis may compensate for the imbalance in the coronal plane of the spine by altering the knee and pelvis in the coronal plane to maintain their center of gravity. Such compensatory effects over time may affect the biomechanical parameters of the lower limbs.

We further analyzed the lower-limb parameters. Márkus et al. [29] found that changes in lower limb and femur length on the main curved side occur in adolescents with idiopathic scoliosis. It is thought that this is because the age of onset of scoliosis is close to a critical skeletal developmental period (before the age of 10) and that the differences are more pronounced when the onset of scoliosis is closer to this age. In the present study, a similar phenomenon was observed when the lower limb parameters of the degenerative scoliosis group were compared with those of the control group. A significant difference was found between scoliosis patients and the control group in terms of the bilateral differences in total lower limb length and femur length, indicating that the lower limb length and femur length on the side of the main curve (the side where the center of gravity is shifted) were less than those on the opposite limb. This led us to speculate that the influence of coronal imbalance in the spine affects the lower limb not only at the stage of skeletal growth and development, but also that the long-term stress asymmetry in the lower limb caused by coronal imbalance is one of the main factors affecting its biomechanical parameters. In conclusion, there is a change in femur length on the main curved side (the side where the center of gravity shifts), and the reduction in femur length leads to a reduction in the total lower limb length. In terms of the other parameters, we found no statistical differences from the CG for ΔHKAA, ΔMPFA, ΔLDFA, and ΔLDTA.

The severity of knee osteoarthritis is usually graded using the KL classification, which is based on anteroposterior radiographic findings, and is also graded as a validated classification system for degenerative joint disease [30]. Similarly, the Takakura scale has been used in many studies for quantitative assessment to determine the extent of subtalar joint degeneration [31]. Smith et al. [32] found that adult patients with symptomatic lumbar scoliosis had a high orthopedic disease burden and a higher rate of total knee arthroplasty than the general population at the same age. By comparing the quantified degeneration of the knee and ankle joints, we found that the scoliosis group showed significantly higher degeneration than in the CG. In addition, our results showed that knee and ankle degeneration was significantly more severe on the main curved side of the scoliosis than on the opposite side. This indicates that in patients with degenerative scoliosis, an imbalance in the coronal plane leads to unbalanced stress in both lower limbs, which may contribute to the degeneration of the lower limb on the main curved side.

This study has some limitations. First, because we used only EOS 2D-based analysis, we were unable to compare pelvic and lower limb torsion. This could be solved by further EOS 3D reconstruction. The present study is a cross-sectional study, and there is a lack of data on whether participants developed knee joint degeneration or scoliosis first. Therefore, the relationship between the severity of lower-limb knee and ankle degeneration and degenerative scoliosis cannot be fully elucidated. Further longitudinal studies are required to clarify this. The number of cases involved in this study was small, and a multicenter, more extensive study is needed to provide more convincing data.

Conclusion

The results of the present study showed altered biomechanical parameters in the lower limbs of patients with degenerative scoliosis. The lengths of the femur and the entire lower limb were reduced on the side of the main curve (the side where the center of gravity is shifted), and both the knee and ankle joints were more severely degenerated on the side of the main curve than on the opposite side. In patients with degenerative scoliosis, a coronal imbalance may need to be corrected in time to avoid adverse effects on the lower limbs, although these differences may be asymptomatic for a short period of time. This finding provides a new consideration for current treatment strategies for degenerative scoliosis.

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Disclosure of conflict of interest

None.

Address correspondence to: Dr. Liang Yan, Department of Spine Surgery, Honghui Hospital, Xi'an Jiaotong University, 555 Youyi East Road, Beilin District, Xi'an 710000, Shaanxi, China. Tel: +86-029-87890270; Fax: +86-029-87894724; E-mail: yanliangdr5583@163.com

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