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*Original Article*

# Gender differences in degenerative lumbar scoliosis spine flexibilities

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**Abstract:** Objectives: The incidence of adolescent idiopathic scoliosis is higher in girls, but spine deformities are more severe in boys. We aimed to identify gender differences of mechanical factors involved in adult degenerative scoliosis (DS). Methods: 20 male (60.35±6.77 years) and 19 female (58.89±9.15 years) specimens of cadaveric lumbar spines were divided into 3 groups comprised of a Cobb angle >10° (DS), a Cobb angle <10° but >3° (pre-degenerative scoliosis (PS)) and intervertebral disc angles <3° in which the Cobb angle could not be measured (non-degenerative scoliosis (NS)), respectively. Spine data were collected for flexion/extension (FE), lateral bending (LB), axial torsion (AT), range of motion (ROM), neutral zone (NZ) and the neutral zone ratio (NZR). Results: There was no significant difference regarding the severity of DS between male and female specimens. Only in males were $ROM_{AT}$ ($P$=0.001), $NZ_{AT}$ ($P$<0.001), $NZ_{FE}$ ($P$=0.045), $NZ_{LB}$ ($P$=0.002) as well as $NZR_{AT}$ ($P$<0.001) and $NZR_{LB}$ ($P$=0.001) values significantly lower in right compared to left scoliosis. With the exception of $ROM_{AT}$ in DS specimens, $ROM_{AT}$, $ROM_{FE}$ and $ROM_{LB}$ values were significantly higher in females than those in males for the DS, PS and NS specimens. $NZ_{AT}$, $NZ_{FE}$ and $NZ_{LB}$ values were significantly higher in PS and NS female specimens. $NZR_{AT}$ was significantly lower in female DS specimens ($P$=0.031) and significantly higher in female PS specimens ($P$=0.031) compared to that in male specimens. Conclusions: In lumbar scoliosis specimens, the rigidness of spines was higher in males than in females and more pronounced in right than in left scoliosis, but only in males.

**Keywords:** Biomechanics, degenerative scoliosis, initial scoliosis nature, occurrence, development

## Introduction

Scoliosis in adults is a common term including any form of scoliosis in mature individuals regardless of whether the deformity begins before or after skeletal maturity [1]. Common forms comprise adult idiopathic scoliosis (AdIS) and de novo adult degenerative scoliosis (ADS); the former occurs as a continuation of adolescent idiopathic scoliosis and the latter is caused by progressive degenerative changes [2].

Degenerative scoliosis (DS) is the constitutional alignment of the spinal column caused by degeneration of the intervertebral discs and facet joints after skeletal maturation in which the coronal Cobb angle is greater than 10° [3-5]. As the lumbar and thoracolumbar spinal segments are usually affected [6], it can also be called degenerative lumbar scoliosis (DLS). Xu and colleagues [7] reported that the prevalence of DS in a Chinese Han population of individuals over 40 years of age was approximately 13.3% and it increased with age. The basic pathophysiology of DS remains unclear, but most scholars believe that the pathological basis is asymmetric intervertebral disc and facet joint degeneration, leading to vertebral tilt and abnormal activities, resulting in spinal instability and asymmetry as well as the formation of three-dimensional spinal deformities [8]. Studies conducted by Murata and colleagues [9] reported that lumbar disc degeneration in any segment was likely to be a trigger for degenerative lumbar scoliosis. Present studies have considered age [10], gender [7], race [11], osteoporosis [12], lumbar lateral listhesis [13], relationship of L5 to the intercrest line [14] rotatory deformity and lateral spondylolisthesis of the L3 vertebra [15, 16] as well as a smaller L4

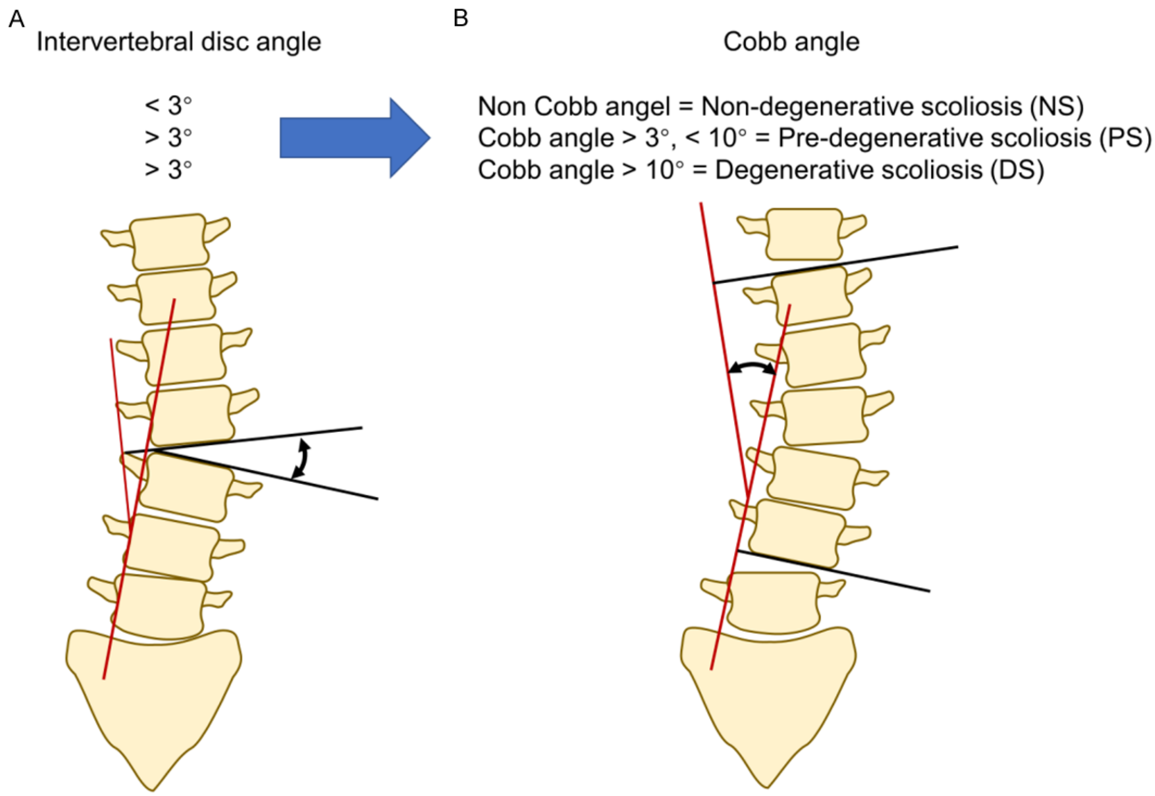


**Figure 1.** Scheme for the diagnosis of the severity of scoliosis. A. Measurement of wedge angle in the intervertebral space; B. Measurement of the Cobb angle in a case where the intervertebral disc angle was >3°.

size and L4 tilt at baseline [10] to be potential factors that lead to the progressive increase of scoliosis. Various studies have reported that the incidence of adolescent idiopathic scoliosis was higher in girls than in boys, though its severity was greater in boys [17-22]. However, less information has been published on gender differences of DS and therefore in the present study gender differences of spine range of motion (ROM) and neutral zone (NZ) values in specimens with DS were evaluated.

## Materials and methods

The present research was carried out in the Spine and Biomechanics Laboratory, Department of Neurosurgery, Allegheny Health Network in the USA. Since the cadaveric investigations did not involve human subjects, institutional review board approval for research presented in this article was not necessary. Thirty-nine frozen human lumbar spine specimens of 20 males and 19 females from T12 to S1 were obtained following institutional approval of the Department of Neurosurgery of the Allegheny Health Network.

The fresh cadaveric whole lumbar spines from T12 to S1 specimens were sealed in double plastic bags and frozen at -20°C until required for analysis. Before testing, the specimens were thawed for 24 h at room temperature. The musculature and soft tissue were removed from each specimen but sparing the osteoligamentous structures. Each specimen was fixed onto 2 potting rings at T12 and the sacrum, making sure the rings and specimen were aligned. A total of 195 functional spinal units (FSU) were tested (from L1 to S1). All specimens were scanned by computed tomography (CT) at a 0.6 mm resolution and the images imported into ScanIP (version 6.0, Simpleware, Exeter, UK) in order to create 3-D models of the vertebral bodies. The intervertebral disc angles (angle between the tangential lines of the inferior endplate of a vertebra and the superior endplate of the next vertebra) (**Figure 1A**) were measured. If the intervertebral disc angle was

**Table 1.** Basic characteristics

| | Male (n=20) | Female (n=19) | *P*-value |
|---|---|---|---|
| Age (years), mean ± SD | 60.35±6.77 | 58.89±9.15 | 0.574 |
| Different scoliosis, n (%) | | | 0.999 |
| NS | 12 (60.0) | 13 (68.4) | |
| PS | 5 (25.0) | 4 (21.1) | |
| DS | 3 (15.0) | 2 (10.5) | |
| FSU, n | | | 0.497 |
| NS | 58 | 61 | |
| PS | 24 | 19 | |
| DS | 15 | 10 | |
| Scoliosis orientation, n (%) | | | 0.580 |
| Left | 6 (75.0) | 3 (50.0) | |
| Right | 2 (25.0) | 3 (50.0) | |
| Scoliosis apex, n (%) | | | 0.180 |
| L1-2 | 0 (0.0) | 1 (16.7) | |
| L2-3 | 3 (37.5) | 0 (0.0) | |
| L3-4 | 1 (12.5) | 3 (50.0) | |
| L4-5 | 4 (50.0) | 2 (33.3) | |

Abbreviations: DS, degenerative scoliosis; FSU, functional spinal unit; NS, non-degenerative scoliosis; PS, pre-degenerative scoliosis.

more than 3°, the lumbar spine Cobb angle was measured from the upper-level vertebra to the lower-level vertebra (**Figure 1B**). In cases where the intervertebral disc angles were <3° the spines were considered to comprise non-degenerative scoliosis (NS). If the intervertebral disc angles were >3° and the Cobb angles <10° but >3° the spines were considered to represent pre-degenerative scoliosis (PS) whereas a Cobb angle >10° indicated DS.

*Kinematic measurements*

The locations and orientations of the vertebrae were monitored using a motion capture system (Optotrak, Northern Digital Instruments, Waterloo, ON, Canada). Kinematic data were obtained for flexion extension (FE), lateral bending (LB) and axial torsion (AT) using a 6-degree-of-freedom spine tester (Bose, Smart Test Series, Eden Prairie, MN, USA), with 3 cycles of sinusoidal loading (max ±7.5 N, 0.005 Hz); data from the 3$^{rd}$ cycle were used for analyses.

Euler angles were calculated from each vertebral tracking body to its inferior neighbor in the sequence Xy'z". The FE ROM, LB ROM and AT ROM were defined as the ranges of the first Euler angle (α, corresponding to the X axis), the second Euler angle (β, corresponding to the y' axis) and the third Euler angle (γ, corresponding to the z axis). The NZ was a measure of residual vertebral motion from the neutral position at the beginning of the third load cycle under zero load. The neutral zone ratio (NZR) was the quotient of NZ and ROM.

*Statistical analysis*

All statistical analysis was conducted using SPSS (Version 22, IBM, Armonk, New York, USA). The differences of ROM, NZ and NZR between different scoliosis orientation and scoliosis angle sizes were analyzed using one-way ANOVA with a post hoc Bonferroni correction. The differences of ROM and NZ between different scoliosis positions are represented by curves. Statistically significant differences were defined as a *P*-value <0.05.

## Results

The specimens were obtained from 3 Negroid and 36 Caucasian individuals whose ages were 60.35±6.77 years for males (n=20) and 58.89±9.15 years for females (n=19). There were no significant gender differences regarding scoliosis grading and FSU numbers as well as for the orientation and scoliosis apex locations (**Table 1**).

*Biomechanical effect of scoliosis orientation on scoliosis*

In the DS and PS groups combined, 9 specimens had left orientation scoliosis and 5 right orientation scoliosis. There were 187 FSUs from which the ROM data were derived and 186 FSUs from which the NZ and NZR data were derived.

There was no difference in ROM data between left and right scoliosis orientation in females, but in males the range of motion-axial torsion ($ROM_{AT}$) was significantly lower in right scoliosis ($P<0.001$). Otherwise, the $ROM_{AT}$, range of motion-flexion extension ($ROM_{FE}$) and the range of motion-lateral bending ($ROM_{LB}$) values were all significantly higher in females than in males ($ROM_{FE}$: $P_{Left}=0.001$, $P_{Right}=0.005$; $ROM_{LB}$: $P_{Left}<0.001$, $P_{Right}=0.001$). Similarly, neutral zone-axial torsion ($NZ_{AT}$), neutral zone-flexion extension ($NZ_{FE}$) and neutral zone-lateral bending ($NZ_{LB}$) values in right scoliosis were significantly higher in females than in males ($P$=0.005, $P$=0.006, $P$<0.001, respectively), an apparent trend also visible for left scoliosis but without statistical significance. In males, all $NZ_{AT}$, $NZ_{FE}$ and $NZ_{LB}$ values were significantly lower in right scoliosis compared to left scoliosis ($P$<0.001, $P$=0.045, $P$=0.002, respectively). $NZ_{AT}$, neutral zone ratio-axial torsion ($NZR_{AT}$) and neutral zone ratio-lateral bending ($NZR_{LB}$) values were similar in left scoliosis of both genders, but lower in males than in females. $NZ_{AT}$ and $NZR_{LB}$ were significantly lower in right than in left scoliosis only for males (both $P$<0.001) (**Table 2**).

*Biomechanical effect of the scoliosis angle on scoliosis*

With the exception of $ROM_{AT}$ in DS specimens, all other $ROM_{AT}$, $ROM_{FE}$ and $ROM_{LB}$ values were significantly higher in females than in males for all DS, PS and NS specimens ($ROM_{AT}$: $P_{PS}$ <0.001, $P_{NS}$=0.002; $ROM_{FE}$: $P_{DS}$=0.019, $P_{PS}$ <0.001, $P_{NS}$ <0.001; $ROM_{LB}$: $P_{DS}$=0.005, $P_{PS}$ <0.001, $P_{NS}$ <0.001). $ROM_{AT}$ differed significantly between the 3 groups in female and male specimens ($P$=0.012, $P$=0.002, respectively), but $ROM_{LB}$ values were only significantly different between the groups for females ($P$=0.012). $NZ_{AT}$, $NZ_{FE}$ and $NZ_{LB}$ values were significantly higher in females in the PS and NS specimens (all $P$<0.05), but only $NZ_{LB}$ was significantly different within the female groups ($P$=0.008), whereas only $NZ_{AT}$ differed significantly within the male groups ($P$<0.001). $NZR_{AT}$ was significantly lower in the female DS samples, which was due to similar $ROM_{AT}$ but higher $NZ_{AT}$ values of male specimens. For PS specimens, significantly greater $ROM_{AT}$ values in combination with significantly greater $NZ_{AT}$ data led to a significantly higher $NZR_{AT}$ value in females (both $P$=0.031). With the exception of $NZR_{FE}$ in male specimens all other $NZR_{AT}$, neutral zone-flexion extension ($NZR_{FE}$) and $NZR_{LB}$ values were different in the 3 groups (all $P$<0.05) (**Table 3**).

*Biomechanical effects of scoliosis apex positions on spine flexibilities*

The scoliotic spine had the least $ROM_{AT}$ when its apex was located at the L2-3 level and exhibited the largest $ROM_{FE}$ and $ROM_{LB}$ values when its apex was located at the L3-4 level. The apex level, however, did not have the largest ROM of the entire spine (**Figure 2A-C**). The scoliotic spine had the least $NZ_{AT}$ when its apex was located at the L2-3 level and had the largest $NZ_{FE}$ and $NZ_{LB}$ when its apex was located at the L3-4 level (**Figure 2D-F**).

Taken together, the results showed that the spine ROM in men with DS was worse than that in women. Especially degenerated right spinal curvatures due to the DS were more rigid in men and the difficulty of orthopedic surgery may be greater in males than in females.

## Discussion

To evaluate the factors that affect the occurrence and development of DS, researchers have performed imaging studies through clinical follow-ups [7, 10, 16, 23], but biomechanical research literature has rarely been published. Unlike adolescent idiopathic scoliosis, DS has mild coronal Cobb angles, mostly within 10-20° [8, 24]. In the present study, we carried out biomechanical tests on NS, PS and mild to moderate DS with Cobb angles <15° to determine the biomechanical characteristics. The total ROM of a spinal segment is commonly divided into neutral and elastic zones. For spinal stability the NZ must be stabilized and motions occurring within the NZ must be controlled in order to maintain the size of the neutral zone. Instability of the spine develops when the NZ increases relative to the ROM, which is expressed by the NZR formula [25, 26]. In a recent study on whole trunk NZ quantification of scoliotic lumbar spines, especially the axial twist, NZ was significantly greater in scoliosis specimens [27], which was reflected in significantly higher $NZ_{AT}$ and $NZR_{AT}$ values of male compared to female DS specimens in the present study. Otherwise, ROM values were generally higher in females than those in males, but this was accompanied by usually higher NZ values, leading to more similar NZR values between genders. In particular, $ROM_{FE}$ values were significantly lower in male than those in female NS, PS and DS specimens, indicating generally higher stiffness in males [28].

Different findings were found during the clinical follow-up process regarding the role of scoliosis orientation in the development of DS. Some scholars believe that the initial orientation of scoliosis is not correlated with the progression of scoliosis [15], while Chin and colleagues [29]

**Table 2.** Comparison of ROM, NZ and NZR between different scoliosis orientations

| | | ROM | $ROM_{AT}$ | $ROM_{FE}$ | $ROM_{LB}$ | NZ | $NZ_{AT}$ | $NZ_{FE}$ | $NZ_{LB}$ | NZR | $NZR_{AT}$ | $NZR_{FE}$ | $NZR_{LB}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Left scoliosis | Female | FSU, n=15 | 6.33±1.98 | 12.30±3.62 | 11.12±1.94 | FSU, n=14 | 1.43±1.02 | 3.48±2.36 | 3.07±2.56 | FSU, n=14 | 0.21±0.09 | 0.28±0.15 | 0.26±0.18 |
| | Male | FSU, n=29 | 4.71±2.99 | 8.38±3.20 | 7.93±2.33 | FSU, n=29 | 1.17±0.91 | 2.25±1.97 | 1.77±1.41 | FSU, n=29 | 0.23±0.12 | 0.22±0.15 | 0.22±0.12 |
| | *P*-value | - | 0.066 | 0.001 | <0.001 | - | 0.396 | 0.079 | 0.092 | - | 0.527 | 0.209 | 0.431 |
| Right scoliosis | Female | FSU, n=14 | 5.44±2.29 | 11.36±3.30 | 11.70±3.01 | FSU, n=14 | 1.08±0.92 | 2.57±1.09 | 2.17±0.92 | FSU, n=14 | 0.18±0.10 | 0.23±0.07 | 0.19±0.06 |
| | Male | FSU, n=10 | 2.46±1.05 | 7.71±2.06 | 7.42±2.53 | FSU, n=10 | 0.24±0.20 | 1.34±0.79 | 0.83±0.33 | FSU, n=10 | 0.09±0.04 | 0.17±0.07 | 0.12±0.05 |
| | *P*-value | - | <0.001 | 0.005 | 0.001 | - | 0.005 | 0.006 | <0.001 | - | 0.006 | 0.064 | 0.011 |
| *P*-value (Left *vs* Right) | Female | - | 0.272 | 0.473 | 0.542 | - | 0.351 | 0.204 | 0.230 | - | 0.454 | 0.221 | 0.158 |
| | Male | - | 0.001 | 0.541 | 0.556 | - | <0.001 | 0.045 | 0.002 | - | <0.001 | 0.168 | 0.001 |

Note: Overall differences were compared using ANOVA. Abbreviations: NZ, neutral zone; $NZ_{AT}$, neutral zone-axial torsion; $NZ_{FE}$, neutral zone-flexion extension; $NZ_{LB}$, neutral zone-lateral bending; NZR, neutral zone ratio; $NZR_{AT}$, neutral zone ratio-axial torsion; $NZR_{FE}$, neutral zone-flexion extension; $NZR_{LB}$, neutral zone ratio-lateral bending; ROM, range of motion; $ROM_{AT}$, range of motion-axial torsion; $ROM_{FE}$, range of motion-flexion extension; $ROM_{LB}$, range of motion-lateral bending.

**Table 3.** Comparison of ROM, NZ and NZR between different scoliosis groups

| | | ROM | $ROM_{AT}$ | $ROM_{FE}$ | $ROM_{LB}$ | NZ | $NZ_{AT}$ | $NZ_{FE}$ | $NZ_{LB}$ | NZR | $NZR_{AT}$ | $NZR_{FE}$ | $NZR_{LB}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NS | Female | FSU, n=61 | 4.31±2.58 | 10.64±3.71 | 9.50±2.88 | FSU, n=61 | 0.85±1.11 | 2.39±1.91 | 1.77±1.09 | FSU, n=61 | 0.15±0.08 | 0.20±0.10 | 0.18±0.09 |
| | Male | FSU, n=58 | 3.10±1.34 | 8.19±3.01 | 7.47±2.24 | FSU, n=58 | 0.46±0.36 | 1.68±1.07 | 1.14±0.53 | FSU, n=58 | 0.13±0.06 | 0.19±0.07 | 0.15±0.05 |
| | *P*-value | - | 0.002 | <0.001 | <0.001 | - | 0.011 | 0.014 | <0.001 | - | 0.155 | 0.522 | 0.029 |
| PS | Female | FSU, n=19 | 6.24±2.36 | 11.9±3.57 | 11.42±2.2 | FSU, n=18 | 1.48±1.09 | 3.40±2.13 | 2.96±2.27 | FSU, n=18 | 0.21±0.10 | 0.29±0.13 | 0.25±0.16 |
| | Male | FSU, n=24 | 3.48±1.84 | 8.03±2.94 | 7.49±2.62 | FSU, n=24 | 0.66±0.72 | 1.96±1.61 | 1.52±1.29 | FSU, n=24 | 0.15±0.09 | 0.22±0.11 | 0.19±0.11 |
| | *P*-value | - | <0.001 | <0.001 | <0.001 | - | 0.006 | 0.017 | 0.023 | - | 0.031 | 0.076 | 0.146 |
| DS | Female | FSU, n=10 | 5.27±1.58 | 11.73±3.37 | 11.36±3.07 | FSU, n=10 | 0.86±0.55 | 2.35±1.03 | 2.00±0.94 | FSU, n=10 | 0.16±0.07 | 0.20±0.06 | 0.17±0.05 |
| | Male | FSU, n=15 | 5.18±3.72 | 8.48±3.02 | 8.30±1.85 | FSU, n=15 | 1.36±0.98 | 2.11±2.07 | 1.54±1.32 | FSU, n=15 | 0.26±0.13 | 0.19±0.17 | 0.20±0.11 |
| | *P*-value | - | 0.932 | 0.019 | 0.005 | - | 0.156 | 0.713 | 0.354 | - | 0.031 | 0.871 | 0.389 |
| Overall *P*-value in gender groups | Female | - | 0.012 | 0.343 | 0.012 | - | 0.091 | 0.126 | 0.008 | - | 0.031 | 0.010 | 0.025 |
| | Male | - | 0.002 | 0.903 | 0.443 | - | <0.001 | 0.490 | 0.126 | - | <0.001 | 0.566 | 0.038 |

Note: Overall differences were compared using ANOVA. Abbreviations: DS, degenerative scoliosis; NS, non-degenerative scoliosis; NZ, neutral zone; $NZ_{AT}$, neutral zone-axial torsion; $NZ_{FE}$, neutral zone-flexion extension; $NZ_{LB}$, neutral zone-lateral bending; NZR, neutral zone ratio; $NZR_{AT}$, neutral zone ratio-axial torsion; $NZR_{FE}$, neutral zone-flexion extension; $NZR_{LB}$, neutral zone ratio-lateral bending; PS, pre-degenerative scoliosis; ROM, range of motion; $ROM_{AT}$, range of motion-axial torsion; $ROM_{FE}$, range of motion-flexion extension; $ROM_{LB}$, range of motion-lateral bending.

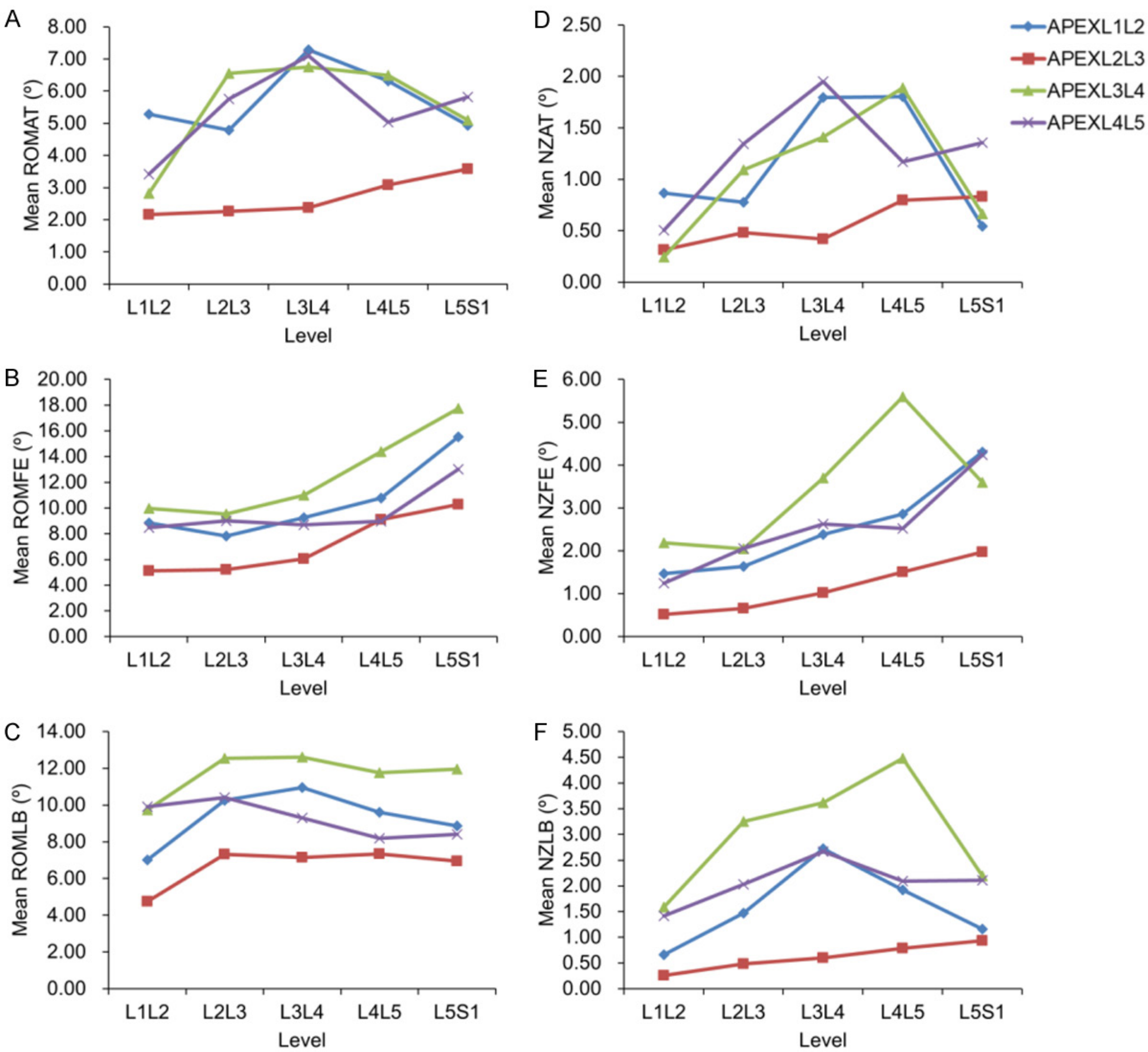


**Figure 2.** $ROM_{AT}$, $ROM_{FE}$, $ROM_{LB}$, $NZ_{AT}$, $NZ_{FE}$ and $NZ_{LB}$ of different scoliosis apex positions of PS and DS specimens. A. $ROM_{AT}$ of different scoliosis apex positions; B. $ROM_{FE}$ of different scoliosis apex positions; C. $ROM_{LB}$ of different scoliosis apex positions; D. $NZ_{AT}$ of different scoliosis apex positions; E. $NZ_{FE}$ of different scoliosis apex positions; F. $NZ_{LB}$ of different scoliosis apex positions. Abbreviations: $NZ_{AT}$, neutral zone-axial torsion; $NZ_{FE}$, neutral zone-flexion extension; $NZ_{LB}$, neutral zone-lateral bending; $ROM_{AT}$, range of motion-axial torsion; $ROM_{FE}$, range of motion-flexion extension; $ROM_{LB}$, range of motion-lateral bending.

studied 24 patients with DS and found that DS with initial left lateral scoliosis would worsen 3° per year and initial right lateral scoliosis would worsen 1° per year. In the present study, $NZR_{AT}$ and $NZR_{LB}$ values in left scoliosis specimens were significantly higher in the left compared to right scoliosis orientation, but only in males.

The higher stiffness of male *vs* female scoliosis specimens and the more pronounced involvement of left scoliosis might be explained by the fact that the musculature is the major active compound for spinal stability, since the movements within and especially beyond the neutral zone are mainly controlled by skeletal muscles [25], which are usually stronger in males.

Several studies have found that the most common apex of DS was located at L3 or L4, while rotatory deformity and lateral spondylolisthesis of the L3 vertebra may be a prognostic factor for DS in the elderly [3, 24]. In contrast, another study reported that the majority of apexes were located at L2-3 [30].

In the present study, we found that the scoliosis with an apex located at L3-4 had the highest $ROM_{FE}$, $ROM_{LB}$, $NZ_{FE}$ and $NZ_{LB}$ values compared to any other apex, which is consistent with the conclusion that L3-4 is the most common subluxation segment through radiological evaluation of DS [31] and supported by other studies in which DS mainly occurred at the interspaces between L3 and L4 or L4-S1 [32]. These results support the theory that a scoliosis apex, located especially at L3-4, will assert more influence on DS than an apex located at any other level. However, data from the present study suggests that scoliosis with an apex located at L2-3 had the lowest ROM and NZ values, which findings require further investigation. Another result was that the vertebral segment apex was not the one where the spine ROM/NZ was largest since it was expected that the scoliosis apex should normally be the most unstable segment in the entire spine.

There are some limitations in our study including the low number of specimens, especially the L1-2 and L2-3 apex, and that only Cobb angles of <15° were included.

## Conclusions

Although scoliosis spines did not differ significantly between different genders regarding severity, in the male they were generally stiffer and there was a significantly greater stiffness in the right compared to left scoliosis orientation, but only in males.

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## Disclosure of conflict of interest

None.

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