

Moderate Degeneration of the Lumbar Paravertebral Muscle in Patients With Dynamic Sagittal Imbalance, A retrospective cohort study

Nan Ru

Shandong Provincial Hospital

Guodong Wang

Shandong Provincial Hospital

Yang Li

Shandong Provincial Hospital

Xingang Cui

Shandong Provincial Hospital

Jianmin Sun (✉ spine2000@msn.com)

Shandong Provincial Hospital

Research article

Keywords: dynamic sagittal imbalance, sagittal imbalance, spinal-pelvic parameters, paravertebral muscle, fat infiltration

Posted Date: August 21st, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-51797/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Study Design: A retrospective cohort study.

Background: Sagittal imbalance of the spine is a comprehensive concept and can be caused by many causes. Paravertebral muscle is an important factor in the stabilization of spine. The active subsystem formed by the muscles around the lumbar spine plays an important role in maintaining lumbar spine stability and extending the spine. Clinically, we found that some patients showed spinal sagittal balance when they were energetic, but hunched or leaning forward after a period of walking or working. Standing full-spine lateral digital radiographs shows increased sagittal vertical axis (SVA) dynamically. We call this symptoms a dynamic sagittal imbalance—DSI. However, the sagittal sequence, paravertebral muscle changes, and the correlation between them in DSI patients have not been clearly explored. The purpose of this study was to investigate the changes of spinal-pelvic parameters; paravertebral muscle; and the relationship between the two in DSI patients.

Method: The study group comprised 31 patients with DSI and 42 control patients. All subjects underwent radiologic whole spine X-ray examination and lumbar MRI (Magnetic Resonance Imaging) scanning. Spinal-pelvic parameters such as sagittal vertical axis (SVA), thoracic kyphosis (TK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT) and pelvic incidence (PI) was measured. The cross-sectional areas—CSA—of the erector spinae (ES), multifidus (MF), and vertebral body were measured at L2/L3 and L4/L5. The fat infiltration (FI) and relative cross-sectional area (RCSA) of muscle of these muscles were quantitatively measured through Image J. All subjects were examined for bone mineral density and pulmonary function to test the overall skeletal muscle capacity.

Result: Compared with the control group, the DSI group had a smaller lumbar lordosis—more severe fat infiltration and lower Relative functional cross-sectional area (RFCSA) of paravertebral muscle ES (erector spinae) & MF (multifidus). There was no correlation between muscle degeneration and spinal-pelvic parameters in DSI patients. In addition, there were no statistically significant differences in bone mineral density test and pulmonary function test which reflected systemic skeletal muscle capacity of whole body.

Conclusion: DSI—along with moderate degeneration of the paravertebral muscles of the lumbar spine. Usually accompanied by a reduction in lumbar lordosis. DSI is regarded as the pre-state of PDSI.

Background

Sagittal imbalance of the spine is a comprehensive concept and can be caused by many causes. In appearance, it is often manifested as body leaning forward instability; whereas on standing full-spine lateral digital radiographs—it shows increased SVA. C7PL-SVA (C7 plumb line-sagittal vertical axis) > 5cm was defined as sagittal imbalance of the spine. (32)(33) Sagittal imbalance can result from a number of causes, such as Ankylosing spondylitis, Parkinson's disease, some neuromuscular diseases (Myasthenia gravis, limb girdle dystrophy, etc), and some spine disorders. [34] Among spine disorders, the causes of sagittal imbalance is mainly Spinal Deformity, lumbar spinal stenosis, lumbar spondylolisthesis, thoracolumbar fractures, et al. [28-31] Paravertebral muscle is also considered to be an important factor in the stabilization of spinal sequence. Among them, ES and MF, as active muscles of lumbar spine, play an important role in the extension of the spine in reaction to gravity and body weight to maintaining spinal balance. [4][20]

Clinically, we found that some patients showed spinal sagittal balance when standing, but hunched or leaning forward after a period of walking or working. Standing full-spine lateral digital radiographs shows increased SVA dynamically. These patients often complain of feeling weakness in the lower back, marked hunchback and leaning forward after a period of walking or working without severe lower back pain or neurogenic claudication. Other notable clinical features is as following: 1) Inability to hold things in front of themselves. 2) Support with elbows in order to wash dishes or faces. 3) Difficult in climbing slopes. 4) Preferred to carry things on their back rather than hold them in front of themselves. These symptoms are similar to Degenerative lumbar kyphosis (LDK)—Flat back syndrome—Drop body syndrome. [35-38]

In 1988, Takemitsu et al. introduced the term "lumbar degenerative kyphosis", which included a marked lumbar lordosis or kyphosis caused by degenerative changes in the middle-aged and elderly people, and classified LDK into four types according to the sequence of the spine. [36,37] Takemitsu et al. then reported pathologic features of LDK as marked paravertebral muscle atrophy with adipose infiltration. [18,36] Flat back syndrome, considered to be a rare disease entity in Western countries, which mostly caused by iatrogenic factors, such as after Harrington rod internal fixation surgery. But in Asian countries it is one of the common spinal deformities. [38,39] Although the exact

pathophysiology of flat back has not yet been **explicitated**, extensive degeneration of lumbar extensor muscles are thought to be responsible for the syndrome in most patients. Drop Body syndrome described by Mitsuru et al. was a primary lumbar kyphosis without obvious coronal deformity, accompanied by severe atrophy of the MF muscle and fatty infiltration.[34] Different from the deformity of the spine structure described above (1. PI-LL > 40°; 2. LLK > -10°; 3. Slight deformity of the coronal plane), as well as the obvious sagittal imbalance in the natural standing position (SVA > 5cm or SVA > 10cm), [35,37,40] we found that DSI patients often presented a balanced sagittal plane in the resting position without obvious spinal deformity.

However, there is no systematic study to explore the pathophysiological mechanism of dynamic spinal sagittal imbalance. The Spinal-pelvic parameters, the changes of paravertebral muscles, whether there is a correlation between the two above, and whether there is a degeneration of the systemic muscle capacity of individuals, have not been systematically elucidated.

Method

Demographic characteristics

470 outpatients and inpatients at the Department of Spine of the authors' facility from March 2018 to May 2020 were recruited. VAS and ODI scores were routinely collected. Any Participants with ankylosing spondylitis, spinal arthrodesis, post-traumatic kyphosis or compression fractures, and neuromuscular disease are excluded. Participants were asked to fill in the form 1. For a diagnosis of DSI, the patient must meet one major criterion and/or more than one minor criterion. Finally, the total of 31 patients was included as the DSI groups. Among the remaining 438 Participants, Control subjects included in this group had no history of chronic low back pain (VAS score > 3), a history of neurogenic claudication and a history of spinal surgery. Finally, a total of 42 people were selected for the control group. This study protocol was approved by the Ethics Committee of our institution.

Spinal-pelvic parameters

All subjects underwent radiologic whole spine X-ray examination in the natural standing position. Spinal-pelvic parameters such as sagittal vertical axis (SVA), thoracic kyphosis (TK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT) and pelvic incidence (PI) was measured. Lordosis was defined negative and kyphosis was defined positive. The method of measuring the angle is Cobb method.

Paravertebral muscle evaluation

All subjects underwent MRI (Magnetic Resonance Imaging) examination of lumbar area. Magnetic resonance imaging was performed using 1.5T Magnetom Vision (Magnetom Symphony; Siemens, Berlin, Germany) scanners. Five T2-weighted (Repetition time/echo time = 3,500–3,600/112–120 ms) axial images from L1/L2 to L5/S1 level were obtained from MRI. Paravertebral muscles were evaluated from the center slice of each of the 5 images.

The scale was marked in the original T2-weighted axial images, then images were imported into Image J (Version 1.52a, National Institutes of Health, USA) for analysis. Four regions of interest (ROI) for the muscles were manually defined at the center slice of each of the 5 images: the ROI for the multifidus, the erector spinae muscle were defined bilaterally. Total CSA (cross-sectional area) was estimated. According to the method proposed by Ranson and Seung-Jae Hyun [3,25], the muscle fat infiltration (FI) area was estimated using the subcutaneous fat threshold as the standard. (Fig. 2) Then the functional CSA (FCSA, lean muscle) of each muscle was calculated by Total CSA minus the fat infiltration area. In order to compensate for the bias of individual relative body size to muscle CSA, we calculated relative CSA (RCSA) (25), i.e. dividing the each muscle FCSA by the CSA of the upper endplate of L5. The fat infiltration rate (FI), RTCSA (Relative total cross-sectional area), RFCSA (Relative functional cross-sectional area) of each muscle at L2/L3 level and L4/L5 level was calculated. Each image was assessed twice by two independent spinal surgeons, and the average value was calculated as the final result.

Bone mineral density (BMD) test and pulmonary function test (PFT)

All subjects were examined for bone mineral density and pulmonary function in order to test the skeletal muscle capacity of the whole body. [27] Bone mineral density was measured at the lumbar spine and left femoral neck by dual-energy X-ray absorptiometry (DEXA, GE Medical Systems Lunar). The BMD of the left femoral neck of the patient was selected for comparison. PFTs were measured with a computerized spirometer with an accuracy of ± 3%. The absolute peak expiratory flow (PEF) and percent-predicted values (ppPEF) were assessed for each participant. The American Lung Association (ALA) scale was used to categorize ppPEFs into the following zones: green (normal), ppPEF > 80%; yellow (mild decline), 50–79%; red (severe decline), < 50%. [26]

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Science (SPSS Inc., Chicago, IL), Version 12.0. The Mann-Whitney U test was used to assess for differences in the demographic data, the Relative total CSA, Relative functional CSA and the rate of fat infiltration between the DSI groups and control groups. The correlation between individual muscle degeneration at L2/L3 and L4/L5 level and spinal-pelvic parameters in DSI groups and control groups was analyzed by Spearman correlation test independently. ALL the data is presented as mean values \pm SEM (standard error of the mean). P-value $<$ 0.05 was considered to be statistically significant.

Result

Demographic data

The DSI group comprised 3 men and 28 women (age, 64.1 \pm 5.1 yo; height, 159.8 \pm 6.3cm; and BMI, 25.0 \pm 3.3). The control group comprised 2 men and 40 women (age, 60.8 \pm 5.3y; height, 158.3 \pm 6.4cm; and BMI, 23.9 \pm 3.4). There were no significant differences in age, body weight, height, or BMI between the 2 groups (Table 1). The DSI group—ranging from 1.25 years to 28 years—9.8 \pm 7.5y—had a longer history of low back pain than the control group—ranging from 0.3 years to 20 years—4.8 \pm 5.0y—. However, there were statistically significant differences in age and history of low back pain between the two above groups.(Table. 2)

Spinal-pelvic parameters

There were no significant differences in TK, TLK, PT, PI, SS or SVA between two groups. However, there were statistically significant differences in LL between the two above groups. The DSI group—ranging from -37.9 to 36.1—-6.5 \pm 24.1—had a lower LL than the control group—ranging from -55.6 to 21.7—-22.4 \pm 20.5—(Table.3)

Paravertebral muscle changes

There were statistically significant differences in FI of MF and ES between the DSI group and control group at L2/L3 (MF, P =0.001; ES, P=0.023) and L4/L5 level—MF, P=0.001; ES, P=0.001—.(Table.4)

The RTCSA of MF and ES was not significantly different between the DSI and the control groups at both L2/L3 (MF, P =0.090; ES, P=0.366) and L4/L5 level (MF, P =0.663; ES, P=0.304). But there were statistically significant differences in RFCSA of MF and ES between two groups at L2/L3 (MF, P =0.045; ES, P=0.016) and L4/L5 level (MF, P =0.001; ES, P=0.002).(Table.5)

The skeletal muscle capacity of the whole body

There were no significant differences in BMD of left femoral neck between the DSI group(0.827 \pm 0.126) and the control group(0.836 \pm 0.132). (Table.2) PFT results for DSI patients indicated that the PEF and ppPEF were in the green range in 51%, the yellow range in 45% and the only one(3%) were in the red range (mean 527 \pm 126L/min and 79 \pm 18%). PFT results for 42 control group patients showed that the PEF and ppPEF were in the green (normal) range in 60%(green), the yellow range (mild decline) in 38% and the red range in 2%. (mean 519 \pm 96 L/min and 80 \pm 14%). There were no significant differences in PEF, ppPEF between two groups.(Table.2)

Correlation analysis

Correlation analysis was conducted between the FI, RTCSA, RFCSA of multifidus, erector spinae, and the spinal-pelvic parameters in the DSI group. Finally—it was confirmed that there was no correlation between muscle degeneration and Spinal-pelvic parameters in both DSI group. (Table. 6)(Table.7)

Discussion

Sagittal balance is a primary issue for clinical assessment of spine.[1]The larger the C7-SVA, the worse the HRQOL(Health related quality of life).[2]Skeletal structure and paravertebral muscles of spine play an important role in maintaining spinal stability. Among them, ES and MF of lumbar spine were considered important in paravertebral muscles[20]Their function is the extension of the spine in reaction to gravity and body weight as well as the maintenance of lumbar spine stability, degeneration of them can cause instability of the spine.[4]Paravertebral muscles degeneration is characterized by a decrease of muscle size and infiltration of fat tissue.[5,6]

This study described a common clinical symptom and investigated its demographic characteristics, spinal-pelvic parameters, and paravertebral muscle degeneration.

Demographic characteristics

In present study, the DSI group was older and had a longer history of low back pain than the control group.

Many factors contribute to the tendency of older people to sagittal imbalance. LG Lenke et al. described increasing age correlated to a more forward sagittal vertical axis with loss of distal lumbar lordosis[7].

Paul S Sung confirmed the stability index of the spine significantly decreased during low back pain—a trunk muscle imbalance may contribute to unbalanced posture. In our previous study, we also demonstrated that severe low back pain due to lumbar disc herniation can lead to sagittal imbalance in some patients, and a decrease in the EMG activity of the lumbar paravertebral muscles can be founded.[8,9]

In this study, The VAS score of both the DSI group and the control group was controlled under 3 score, and there was no statistical difference. We do not believe that the symptoms of DSI are caused by low back pain.

Spinal-pelvic parameters

In present study, the DSI group had a smaller lumbar lordosis than the control group, with no statistically significant difference in other Spinal-pelvic parameters (such as TK, TLK, PT, PI, SS). Different from the previous research—Jee-Soo Jang, Bae J S et al. demonstrated that the change of thoracic kyphosis, thoracolumbar (T-L) junction angle, spinal-pelvic parameters play important roles in compensating the sagittal imbalance in LDK patients.[10,11] Many factors could cause lumbar kyphosis, such as muscle degeneration, disc degeneration, post-laminectomy iatrogenic kyphosis, and vertebral fracture.[12,13] However, in present study, it was difficult to explore the cause of the reduction in lumbar lordosis, which may require a long-term longitudinal study. When lumbar lordosis is reduced or lumbar kyphosis occurs, overwork of the lumbar extensor muscles is required to maintain spinal balance.[14] Therefore, in the DSI group, even in the natural standing position, paravertebral muscles are more prone to fatigue, which lead to the sagittal imbalance.

Paravertebral muscle degeneration

Paravertebral degeneration is characterized by a decrease of muscle size and infiltration of fat tissue. In previous studies, degeneration of lumbar paravertebral muscles can be caused by multiple factors, such as low back pain, lumbar disc herniation, spinal stenosis, and changes in spinal structure.[15-18] In this study, we found that the paravertebral muscle MF/ES degeneration in the DSI group, and the paravertebral muscle degeneration in the L4/L5 level was seriously changed. Our conclusion is consistent with that of Weiwei Xia et al.

[18] *The possible reasons we think are as following: 1) two thirds of the lumbar lordosis are located at the last two lumbar levels— $L4S1 = 0.66 \times L1S1$ [19].* Thus, in patients with reduced lumbar lordosis, more morphological changes were present in the L4-S1 lower lumbar spine. L4-S1 segmental kyphosis elongates paravertebral muscles and exacerbates their dysfunction, which leads to the degeneration of paravertebral muscle at L4/L5 level. 2) The paravertebral muscle in lumbar kyphosis has a shorter lever arm length than in lordosis, which may lead to a decreased movement of the lumbar spine. It may lead to disuse atrophy of the paravertebral muscles.[20] 3) Kaan Yaltirik et al. had proved that long-term pressure on the root caused by disc herniation can cause atrophy and degeneration of that muscle group.[17] About 70% of lumbar disc herniation occur in L4/L5 level. In degenerative lumbar diseases, there are usually multiple levels of intervertebral disc herniation or spinal canal stenosis.[14] Therefore, paravertebral muscle degeneration in DSI patients is caused by multiple factors.

The skeletal muscle capacity of whole body

The PFT results and BMD results were all comparable in patients with the DSI and the control. It showed no difference in overall musculoskeletal capacity between the DSI and the control group. Sarcopenia is defined as an age-related decline decline in skeletal muscle mass, usually accompanied by a decrease in bone mineral density.[22] The PFT results in the both groups were even larger than those of the age-matched and sex-matched healthy Chinese volunteers described by Zhong NS et al, which suggesting normal muscle capacity in both patients.[23] These suggests isolated degeneration of the lumbar paravertebral muscles in the DSI group. It is similar to Drop Head Symptoms and Drop Body Symptoms. Both accompanied by segmental kyphosis and severe degeneration of the local extensor muscles.[35,40]

The reason of the DSI

The Drop Body Symptoms described by Mitsuru Yagi presents a fixed sagittal imbalance (SVA $\geq 10\text{cm}$ —accompanied with severe isolated paravertebral muscle degeneration.[35,40] Camptocormia is defined as an involuntary flexion of the throcolumar spine, without fixed kyphosis, which increase during standing and walking, and abate in the supine position. Camptocormia can be caused by many reasons, paravertebral muscle degeneration is an important cause.[34] Kalichman divided paravertebral muscle degeneration into three levels: Grade 1, normal ($\leq 10\%$ fat infiltration); Grade 2, moderate muscle degeneration (10%-50% fat infiltration); Grade 3, severe muscle degeneration ($\geq 50\%$ fat infiltration). [21] Severe FI of lumbar paravertebral muscle was found in both Drop Body and Camptocormia.[34,35] Drop Body and Camptocormia consistently showed immediate leaning forward even when patients were energetic. The DSI tends to lean forward after a period of walking or manual labor. In present study, it can be seen that the fat infiltration rates of L2/L3 level (MF: $41.2\% \pm 10.3\%$ ES: $30.6\% \pm 9.6\%$) and L4/L5 level (MF: $49.6\% \pm 12.3\%$ ES: $34.4\% \pm 7.4\%$) in the DSI group, which was far lower than those described by Drop body and Camptocormia (MF/ES: $\geq 80\%$).

Takemitsu also described that in LDK patients, some patients had leaning forward when they were exhausted, but there was no specific study on the degree of paravertebral muscle degeneration.[14]

Chang-hyun Lee proposed one concept called PDSI (Primary degenerative sagittal imbalance. [4]The diagnosis for PDSI must meeting the following criteria : (1. C7-SVA ≥ 5 cm, 2. pelvic incidence – lumbar lordosis $\geq 15^\circ$, 3. pelvic tilt $\geq 25^\circ$, 4. paravertebral muscle degeneration, 5. Symptoms of spine sagittal imbalance.) Some primary imbalance (such as LDK, Flat back syndrome , Drop body syndrome) were categorized into this concept.[4]

Different from the diagnosis of PDSI, which both imaging diagnosis and clinical symptom diagnosis are required. We focus more on the diagnosis of clinical symptoms. Different from the severe paravertebral degeneration in PDSI patients, DSI have only moderate paravertebral muscle degeneration. The paravertebral muscle degeneration is caused by multiple factors. The function of DSI patients paravertebral muscle was better than that of PDSI patients. When the DSI patient is energetic, the degenerative paravertebral muscles can be actively activated to maintain spinal balance. When paravertebral muscles are fatigue (walking or moving for a period of time), it is difficult to maintain sagittal balance of the spine, resulting in forward leaning or hunchback. And as the lumbar lordosis decreases, the paravertebral muscles need to do more work to maintain spinal balance. Theoretically, patients with reduced lumbar lordosis are more likely to develop DSI symptoms at the same degree of muscle degeneration as compared to normal sagittal sequence. However, severe DSI symptoms can occur even in people with normal sagittal sequence (Fig.3). And as the paravertebral muscle continues to degenerate to a severe degree, even in energetic state, the paravertebral muscles of the lumbar spine are not strong enough to maintain sagittal balance, which leads to a marked leaning forward posture, that is PDSI. There have been no studies to investigate the synergy between lumbar sequence and degenerative paravertebral muscles in patients with sagittal imbalance. Therefore we believe that the DSI described in this study is actually the pre-state of PDSI. (Fig.4).

The study also has some limitations. 1) This study may be limited by the small number of patients enrolled. The reason is the low incidence of DSI, which may require more studies based on a large population of multicenter studies. 2) The radiologic whole spine X-ray was lacked when the DSI patient was exhausted. The changes of sagittal plane sequence before and after the patient's imbalance have not been explored in detail. Junseok Bae had assessed global and regional spinal sagittal radiographic parameters in adults with loss of lumbar lordosis ("flatback") before and after walking 10 minutes, LL, PT, TK has its related compensation mechanism, but the paravertebral muscle changes have not been described.[15] 3) There is no specific method to quantify the severity of symptoms in DSI patients, so we did not explore the correlation between the severity of symptoms and paravertebral muscle degeneration, sagittal plane sequence in DSI patients.

Conclusion

In conclusion, DSI is the pre-state of PDSI, along with moderate degeneration of the paravertebral muscles of the lumbar spine. Usually accompanied by a reduction in lumbar lordosis. A DSI patient is usually characterized by a balanced sagittal sequence when he is energetic, and a gradual forward leaning posture when he is exhausted. As paravertebral muscle continue to degenerate, the DSI may be transformed into a fixed sagittal imbalance. Early diagnosis of DSI and relevant intervention may effectively reverse and delay the occurrence of fixed sagittal imbalance.

Abbreviations

SVA, sagittal vertical axis ; DSI, sagittal imbalance; thoracic TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; LL, lumbar lordosis ; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; CSA, cross-sectional areas; ES, erector spinae ; MF, multifidus; PEF, peak expiratory flow; ppPEF, percent-predicted values; RFCSA, Relative functional cross-sectional area; RTCSA, Relative total cross-sectional area; DLK, Degenerative lumbar kyphosis; ROI, regions of interest; BMD, Bone mineral density; PFT, *pulmonary function test*; HRQOL, Health related quality of life; PDSI, Primary degenerative sagittal imbalance

Declarations

Ethics approval and consent to participate The participants provided written informed consent to participate in this research. The subjects' rights and interests are protected well in the whole process. The research has been approved by Ethics Committee of Shandong Provincial Hospital Affiliated to Shandong University.

Consent for publication The images appearing in Figs. 1, 2, 3 and 4 are published with consent.

Availability of data and materials All datasets on which the conclusions of the manuscript rely were presented in the main paper.

Competing interests The authors declare that they have no competing interests.

Funding This article did not receive any funding.

Authors' contributions JS thought out the study, participated in its design and coordination. NR carried out this study, did the statistics and drafted the manuscript. GW and XC polished the manuscript. YL collected part of the data. All authors read and approved the final manuscript.

Acknowledgements The authors would like to thank Dr. Binghao Bian and Dr. Jianlong Li for the assistance in collecting cases.

References

- (1) Chi-Hung Weng, Chih-Li Wang, Yu-Jui Huang et al. Artificial Intelligence for Automatic Measurement of Sagittal Vertical Axis Using Reset Framework. *J Clin Med*, 2019 Nov 1;8(11):1826.
- (2) Mac-Thiong JM, Transfeldt EE, Mehdood AA, et al. Can C7 plumb line and gravity line predict health related quality of life in adult scoliosis? *J. Spine (Phila Pa 1976)*, 2009, 34(15):E519-E527.
- (3) Ranson CA, Burnett AF, Kerslake R, Batt ME, O'Sullivan PB. An investigation into the use of MR imaging to determine the functional cross sectional area of lumbar paraspinal muscles. *Eur Spine J*. 2006;15:764–7
- (4) Lee C H, Chung C K, Jang J S, et al. 'Lumbar Degenerative Kyphosis' Is Not Byword for Degenerative Sagittal Imbalance: Time to Replace a Misconception [J]. *Journal of Korean Neurosurgical Society*, 2017, 60(2):125-129.
- (5) Ranson CA, Burnett AF, Kerslake R, Batt ME, O'Sullivan PB. An investigation into the use of MR imaging to determine the functional cross sectional area of lumbar paraspinal muscles. *Eur Spine J*. 2006;15:764–73.
- (6) Barker KL, Shamley DR, Jackson D. Changes in the Cross-Sectional Area of Multifidus and Psoas in Patients With Unilateral Back Pain. *Spine (Phila Pa 1976)*. 2004;29:E515–9.
- (7) Gelb D E, Lenke L G, Bridwell K H, et al. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *J. Spine*, 1995, 20(12):1351-8.
- (8) Sung P S, Yoon B C, Lee D C. Lumbar spine stability for subjects with and without low back pain during one-leg standing test. [J]. *Spine*, 2010, 35(16):753-760.
- (9) Liang C, Sun J, Cui X, et al. Spinal sagittal imbalance in patients with lumbar disc herniation: its spinopelvic characteristics, strength changes of the spinal musculature and natural history after lumbar discectomy [J]. *BMC Musculoskeletal Disorders*, 2016, 17(1):305.
- (10) Jang JS, Lee SH, Min JH, et al. Lumbar degenerative kyphosis: radiologic analysis and classifications. [J]. *Spine*, 2007, 32(24):2694-2699.
- (11) Bae J S, Jang J S, Lee S H, et al. Radiological analysis of lumbar degenerative kyphosis in relation to pelvic incidence [J]. *Spine Journal*, 2012, 12(11):1045-1051.
- (12) Schwab F, Lafage V, Farcy J P, et al. Age-related correlation with spinal parameters, pelvic parameters, and foot position. [J]. *Spine* 2006;31(25):1-9
- (13) Glover Jr William C. Posterior global malalignment after osteotomy for sagittal plane deformity: it happens and here is why. [J]. *Spine*, 2013, 38(7):E394.
- (14) Takemitsu Y. Lumbar degenerative kyphosis. Clinical, radiological and epidemiological studies. [J]. *Spine*, 1988, 13.
- (15) Kjaer P, Bendix T, Sorensen J S, et al. Are MRI-defined fat infiltrations in the multifidus muscles associated with low back pain? [J]. *BMC Med*, 2007, 5(1):1-10.
- (16) Fortin M, Lazáry, àron, Varga P P, et al. Association between paraspinal muscle morphology, clinical symptoms and functional status in patients with lumbar spinal stenosis [J]. *European Spine Journal*, 2017.
- (17) GÜdü, Burhan Oral, Yüksel, et al. Volumetric Muscle Measurements Indicate Significant Muscle Degeneration in Single Level Disc Herniation Patients [J]. *World Neurosurgery*, 2018:S1878875018309720.
- (18) Xia W, Fu H, Zhu Z, et al. Association between back muscle degeneration and spinal-pelvic parameters in patients with degenerative spinal kyphosis [J]. *BMC Musculoskeletal Disorders*, 2019, 20(1).

- (19) Roussouly P, Pinheiro-Franco J L . Sagittal parameters of the spine: biomechanical approach[J]. European Spine Journal, 2011, 20(s5):578-585.
- (20) Tveit P, Daggfeldt K, Hetland S, et al. Erector spinae lever arm length variations with changes in spinal curvature.[J]. Spine, 1994, 19(Supplement):199-204.
- (21) Kalichman L, Klindukhov A, Li L, et al. Indices of Paraspinal Muscles Degeneration[J]. Journal of Spinal Disorders & Techniques, 2013:1.
- (22) Cruz-Jentoft A J, Bahat Gülistan, Bauer Jürgen, et al. Sarcopenia: revised European consensus on definition and diagnosis[J]. Age and Ageing(1):1.
- (23) Zheng Jinping, Zhong Nanshan. Normal reference value of *pulmonary function* in Chinese adults.[J]. Chinese Medical Journal, 2002, 115(1):50-54.
- (24) Bae J, Theologis A A, Jang J S, et al. Impact of Fatigue on Maintenance of Upright Posture: Dynamic Assessment of Sagittal Spinal Deformity Parameters After Walking 10 Minutes[J]. Spine, 2017, 42.
- (25) Hyun S J, Bae C W, Lee S H, et al. Fatty Degeneration of Paraspinal Muscle in Patients With the Degenerative Lumbar Kyphosis: A New Evaluation Method of Quantitative Digital Analysis Using MRI and CT Scan.[J]. Journal of Spinal Disorders & Techniques, 2013, 29(10).
- (26) Nunn AJ, Gregg I. New regression equations for predicting peak expiratory flow in adults. BMJ. 1989 ;298(6680):1068-70.
- (27) Oliveira M A, Vidotto M C, Nascimento O A, et al. Evaluation of lung volumes, vital capacity and respiratory muscle strength after cervical, thoracic and lumbar spinal surgery[J]. Sao Paulo medical journal = Revista paulista de medicina, 2015, 133(5):388.
- (28) Kim H J, Shen F, Kang K T, et al. Failure of Pelvic Compensation in Patients with Severe Positive Sagittal Imbalance: Comparison between Static Radiographs and Gait Analysis of Spinopelvic Parameters in Adult Spinal Deformity and Lumbar Stenosis[J]. Spine, 2019, publish ahead of print.
- (29) Shin E K, Kim C H, Chung C K, et al. Sagittal imbalance in patients with lumbar spinal stenosis and outcomes after simple decompression surgery[J]. The spine journal: official journal of the North American Spine Society, 2016, 17(2):175.
- (30) Mazel C, Ajavon L . Malunion of post-traumatic thoracolumbar fractures[J]. Retour Au Numéro, 2018, 104(1S).
- (31) Vialle R, Ilharreborde B, Dauzac C, et al. Is there a sagittal imbalance of the spine in isthmic spondylolisthesis? A correlation study[J]. European Spine Journal, 2007, 16(10):1641-1649.
- (32) Vialle, Raphaël. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects.[J]. Journal of Bone & Joint Surgery American Volume, 2005, 87(2):260.
- (33) Glassman S D, Berven S, Bridwell K, et al. Correlation of radiographic parameters and clinical symptoms in adult scoliosis.[J]. Spine, 2005, 30(6):682-688.
- (34) Lenoir T, Guedj N, Boulu P, et al. Camptocormia: the bent spine syndrome, an update[J]. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society, 2010, 19(8):1229.
- (35) Yagi M, Kaneko S, Yato Y, et al. Drop Body Syndrome -A distinct form of adult spinal deformity[J]. Spine, 2017, 42(16):E969.
- (36) Takemitsu Y, Harada Y, Iwahara T, Miyamoto M, Miyatake Y : Lumbar degenerative kyphosis. Clinical, radiological and epidemiological studies. Spine (Phila Pa 1976) 13 : 1317-1326, 1988
- (37) Jang J S, Lee S H, Min J H, et al. Influence of lumbar lordosis restoration on thoracic curve and sagittal position in lumbar degenerative kyphosis patients.[J]. Spine, 2009, 34(3):280-284.
- (38) Jang J S, Lee S H, Min J H, et al. Changes in sagittal alignment after restoration of lower lumbar lordosis in patients with degenerative flat back syndrome.[J]. J Neurosurg Spine, 2007, 7(4):387-392.
- (39) Potter BK, Lenke LG, Kuklo TR. Prevention and management of iatrogenic flatback deformity.[J]. Journal of Bone & Joint. 2004;86(8):1793-1808.

Tables

TABLE 1. The diagnosis of DSI (Are you experiencing any of these symptoms?)

Major criterion:	Apparent hunchback or forward leaning posture after standing or walking for a while (without severe lower back pain)? YES/NO
Minor criterion:	1.Low back weakness after standing or walking for a while (without severe lower back pain) ? YES/NO
	2.Inability to go uphill, and often needs crutches to walk? YES/NO
	3. Inability to lift heavy objects while walking or standing, YES/NO and more likely to carry heavy objects on back?
	4. Support with elbows in order to wash dishes or face? YES/NO

For a diagnosis of DSI, the patient must meet one major criterion and/or more than one minor criterion .

TABLE 2. Characteristics of the DSI and Control Patients

	PDSI (n=31)	Controls (n=42)	P
Age(y)	64.1±5.1	60.8±5.3	0.008*
BMI(kg/m ²)	25.0±3.3	23.9±3.4	0.176
Heights(cm)	159.2±6.3	158.3±6.4	0.638
LBP history(y)	9.8±7.5	4.8±5.0	0.001*
PETs(ml/min)	527±126	519±96	0.815
ppPEF(%)	79±18	80±14	0.902
BMD(g/cm ³)	0.827±0.126	0.836±0.132	0.508

The values are given as mean±SD.

A P-value of ≤ 0.05 was considered to indicate statistical significance .

TABLE 3. Spinal-pelvic Parameters of the DSI and Control Patients

	PDSI (n=31)	Controls (n=42)	P
TK	23.2±14.5	21.6±17.3	0.640
TLK	12.8±13.0	12.8±9.2	0.648
LL	-6.5±24.1	-22.4±20.5	0.005*
PT	27.0±9.5	23.0±8.7	0.082
PI	50.3±12.0	48.0±11.8	0.592
SS	23.7±10.6	25.0±9.6	0.755
SVA(cm)	1.4±4.0	1.7±3.7	0.639

The values are given as mean±SD.

A P-value of ≤ 0.05 was considered to indicate statistical significance .

Table 4. Fat Infiltration Rate of the Paraspinal Muscles in DSI and Control Patients

Levels	Muscles	DSI (n=31)	Controls (n=42)	P
L2/L3(%)	MF	41.2±10.3	21.6±13.8	0.001*
	ES	30.6±9.6	20.8±17.4	0.023*
L4/L5(%)	MF	49.6±12.3	26.6±14.2	0.001*
	ES	34.4±7.4	20.6±13.2	0.001*

The values are given as mean±SD. *Statistical significance.

ES indicates erector spinae; MF, multifidus.

A P-value of <0.05 was considered to indicate statistical significance.

Table 5. Total RCSA (Total muscle CSA / L4 endplate CSA) and Functional RCSA (Lean muscle CSA / L4 endplate CSA) of the Paraspinal Muscles in DSI and Control Patients

	Levels	Muscles	DSI (n=31)	Controls(n=42)	P
	L2/L3	MF	0.30±0.11	0.25±0.10	0.090
RTCSA		ES	1.74±0.52	1.78±0.33	0.366
	L4/L5	MF	0.66±0.28	0.65±0.15	0.663
		ES	1.29±0.41	1.39±0.38	0.304
	L2/L3	MF	0.17±0.08	0.19±0.08	0.045*
RFCSA		ES	1.42±0.45	1.43±0.45	0.016*
	L4/L5	MF	0.34±0.18	0.48±0.14	0.001*
		ES	0.84±0.27	1.08±0.30	0.002*

RTCSA , Relative total cross-sectional area; RFCSA ,Relative functional cross-sectional area

ES, indicates erector spinae; MF, multifidus.

A P-value of <0.05 was considered to indicate statistical significance.

Table 6. Correlations between RCSA and FI of multifidus and spinal-pelvic parameters in DSI

Groups	Levels		TK	TLK	LL	PI	PT	SS	SVA	LBP history
DSI	L2/L3	FI	R=-0.141	R=0.402	R=0.046	R=-0.110	R=-0.294	R= 0.070	R=-0.103	R= -0.127
			P=0.448	P=0.125	P=0.806	P=0.557	P=0.108	P=0.707	P=0.581	P=0.495
		TRCSA	R=-0.178	R=-0.087	R=-0.042	R=0.069	R=-0.021	R=0.144	R=-0.028	R=-0.131
		P=0.338	P=0.641	P=0.822	P=0.712	P=0.912	P=0.441	P=0.881	P=0.481	
	FRCSA	R=-0.035	R=-0.087	R=-0.118	R=0.041	R=-0.033	R=0.186	R=-0.011	R=-0.136	
		P=0.890	P=0.642	P=0.310	P=0.828	P=0.861	P=0.315	P=0.953	P=0.464	
L4/L5	FI	R=-0.182	R=-0.140	R=0.025	R=-0.019	R=0.248	R=-0.276	R=-0.030	R=-0.131	
		P=0.327	P=0.452	P=0.894	P=0.920	P=0.178	P=0.133	P=0.874	P=0.481	
		TRCSA	R=-0.142	R=0.132	R=-0.269	R=-0.091	R=-0.316	R=0.192	R=0.026	R=-0.265
		P=0.445	P=0.479	P=0.143	P=0.628	P=0.083	P=0.302	P=0.888	P=0.150	
	FRCSA	R=0.002	R=0.127	R=-0.108	R=0.022	R=-0.318	R=0.260	R=0.057	R=-0.117	
		P=0.991	P=0.496	P=0.562	P=0.905	P=0.081	P=-0.158	P=0.762	P=0.531	

Table 7. Correlations between RCSA and FI of erector spinae and spinal-pelvic parameters in DSI

Groups	Levels		TK	TLK	LL	PI	PT	SS	SVA	LBP history
DSI	L2/L3	FI	R= 0.265	R=-0.206	R=0.085	R=0.147	R=0.116	R=0.017	R=0.063	R=0.206
			P=0.150	P=0.267	P=0.650	P=0.431	P=0.536	P=0.929	P=0.737	P=0.265
		TRCSA	R=-0.178	R=-0.087	R=-0.042	R=0.069	R=-0.021	R=0.144	R=0.024	R=-0.131
			P=0.338	P=0.641	P=0.822	P=0.712	P=0.912	P=0.441	P=0.896	P=0.481
		FRCSA	R=-0.179	R=-0.185	R=-0.042	R=0.001	R= -0.062	R=0.132	R=-0.021	R=-0.155
			P=0.336	P=0.318	P=0.821	P=1.000	P=0.741	P=0.479	P=0.909	P=0.406
	L4/L5	FI	R=-0.124	R=0.084	R=0.037	R=-0.278	R=0.210	R=0.053	R=0.191	R=0.184
			P=0.505	P=0.652	P=0.845	P=0.130	P=0.257	P=0.775	P=0.302	P=0.321
			TRCSA	R=-0.276	R=0.142	R=-0.304	R=0.114	R=-0.074	R=0.107	R=-0.126
			P=0.133	P=0.446	P=0.097	P=0.540	P=0.692	P=0.565	P=0.501	P=0.098
		FRCSA	R=-0.265	R=0.132	R=-0.304	R=0.114	R=-0.074	R=0.107	R=-0.199	R=-0.302
			P=0.149	P=0.479	P=0.097	P=0.540	P=0.692	P=0.565	P=0.283	P=0.098

Figures



Figure 1

A. A lateral photograph shows a balanced sagittal position when the patient is energetic. B. After 10-minutes walk it shows a lean forward posture. C. After another 10 minutes of rest it shows a re-balanced sagittal position.

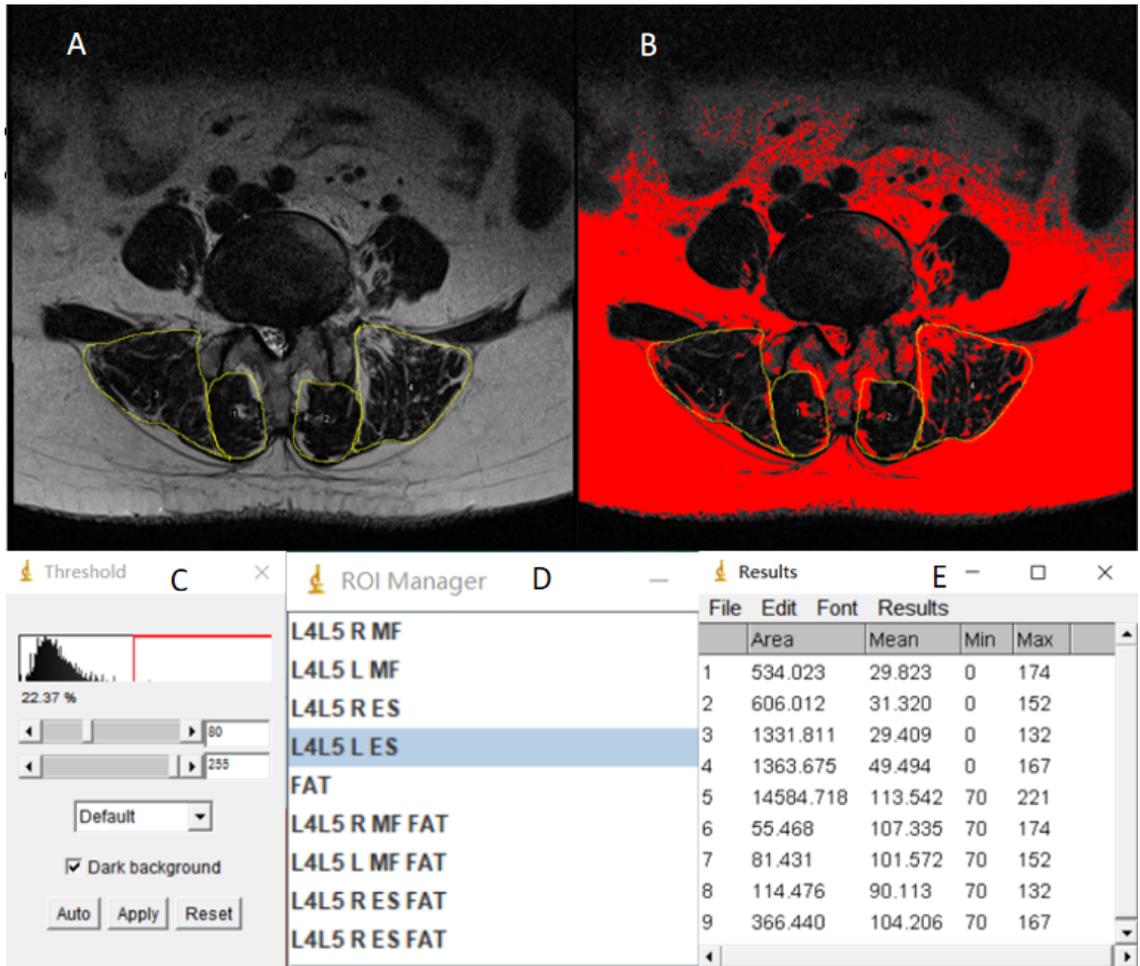


Figure 2

A. The ROI for the multifidus, the erector spinae muscle at L4/L5 level were manually defined. B. C The subcutaneous fat threshold was used as the standard. D.E The fat infiltration area ,TCSA(total cross-sectional area)of each muscle were calculated.

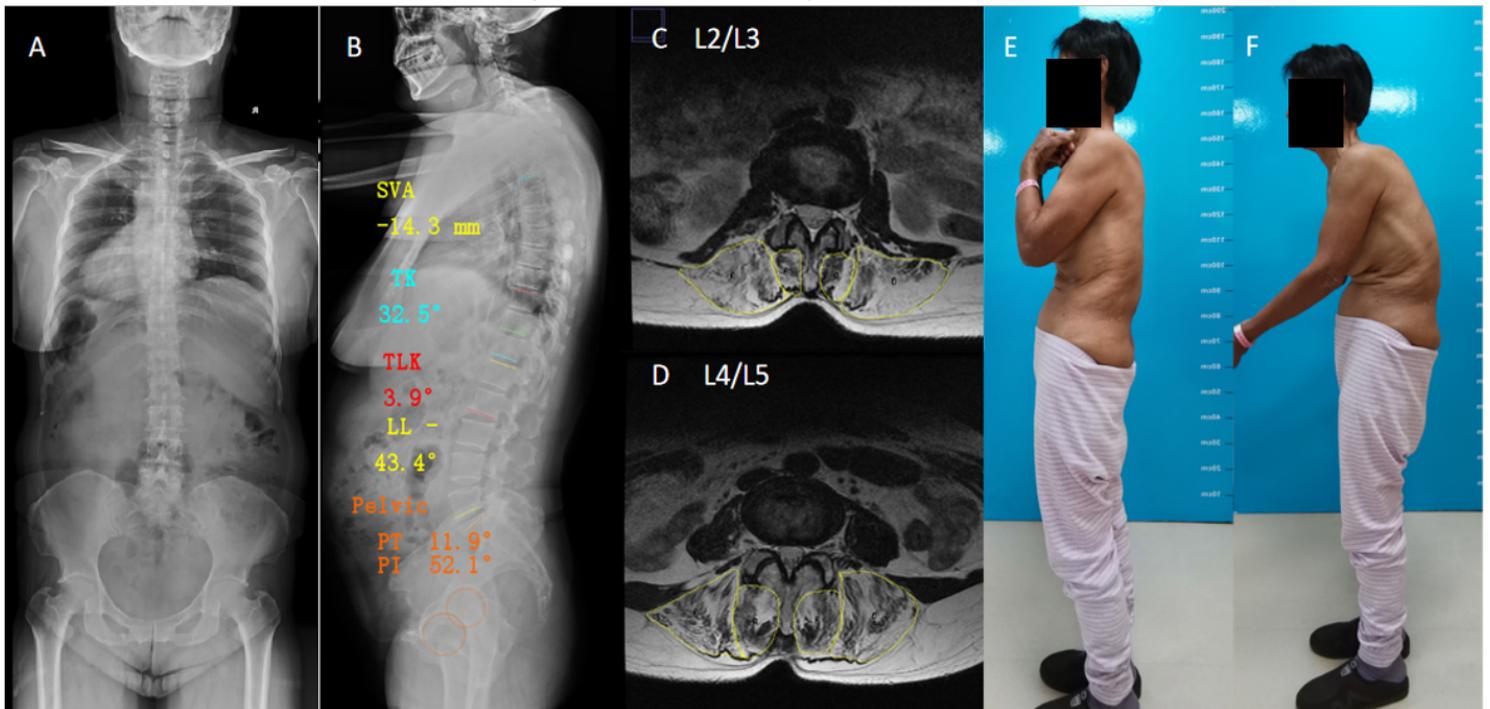


Figure 3

A.B. Anteroposterior and lateral radiographs show normal spinal sequence. C.D. Magnetic resonance imaging show severe paravertebral muscle degeneration at L2/L3 and L4/5 levels.E.A lateral photograph shows a balanced sagittal position when the patient is energetic.F.Lean forward posture within 30-seconds walk.

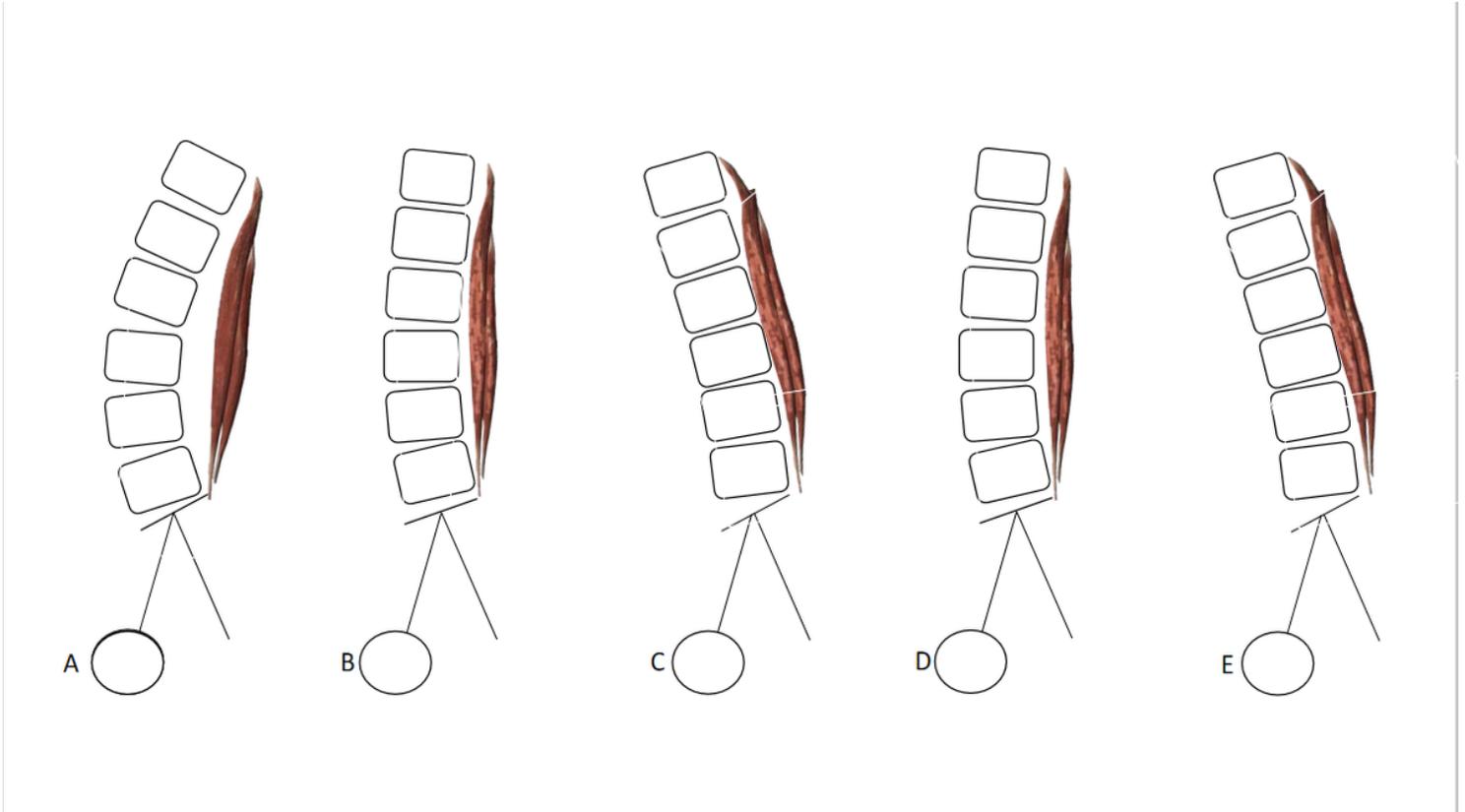


Figure 4

A. Normal: Normal lumbar lordosis with normal paravertebral muscles. B. C. DSI: Reduced lumbar lordosis/lumbar kyphosis with moderate paravertebral muscle degeneration. D. E. PDSI: Reduced lumbar lordosis/lumbar kyphosis with severe paravertebral muscle degeneration.