

Degeneration of the Lumbar Paravertebral Muscle in Patients With Dynamic Sagittal Imbalance, A Retrospective Cohort Study

Nan Ru

Shandong University School of Medicine: Shandong University Cheeloo College of Medicine

Yang Li

Shandong Provincial Hospital

Xingang Cui

Shandong Provincial Hospital

Jianmin Sun (✉ spine2000@msn.cn)

Department of Spine Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University

Guodong Wang

Shandong Provincial Hospital

Research article

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

Posted Date: October 22nd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-94893/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. In appearance, it is often manifested as body leaning forward instability; whereas on standing full-spine lateral digital radiographs, it shows an increased sagittal vertical axis (SVA). Clinically, we found that some patients showed normal sagittal balance at initiation, but hunched or leaned forward after a period of walk or activity. This condition is called dynamic sagittal imbalance (DSI). There is no systematic study to explore the paravertebral muscles changes of dynamic sagittal imbalance.

Method: The study group comprised 31 DSI patients and 42 control patients. All subjects underwent radiologic whole spine X-ray examination and lumbar MRI (Magnetic Resonance Imaging) scanning. Spinal-pelvic parameters at initiation 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 area were measured at L2/L3 and L4/L5. The fat infiltration (FI) and relative cross-sectional area (RCSA) of muscle of these above muscles were quantitatively measured through Image J software.

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 (erector spinae and multifidus). In DSI group, the point-in-time of occurrence of dynamic sagittal imbalance was statistically correlated with degeneration of paravertebral muscles at L4/L5 level, whereas no correlation between the two above at L2/L3 level.

Conclusion: In conclusion, DSI an normal SVA (SVA \leq 40mm) at initiation, and prominent increase in SVA after activity with thunks marked inclined. Paravertebral muscle degeneration plays an important role in the DSI process, Patients in the DSI group had more severe paravertebral muscle degeneration compared with patients in control group. There was a significant correlation between the severity of DSI symptoms and the degeneration of lower lumbar paravertebral muscles. These findings may help spinal surgeons better understand sagittal balance of spine.

Background

Sagittal imbalance of the spine is a comprehensive concept. In appearance, it is often manifested as body leaning forward instability; whereas on standing full-spine lateral digital radiographs, it shows an increased SVA. C7PL-SVA (C7 plumb line-sagittal vertical axis) $>$ 4cm was defined as sagittal imbalance of the spine. [18][19] Sagittal imbalance can be caused by many causes, such as ankylosing spondylitis, Parkinson's disease, some neuromuscular diseases and some spine disorders. [20] Among spine disorders, the causes of spinal sagittal imbalance is mainly spinal deformity, lumbar spinal stenosis, lumbar spondylolisthesis, thoracolumbar fractures, Scheuermann's disease, etc. [14-16,]

Clinically, we found that some patients showed normal sagittal balance at initiation, but hunched or leaned forward after a period of walk or activity. Standing full-spine lateral digital radiographs shows increased SVA dynamically.[12] We called this symptom dynamic sagittal imbalance (DSI). These patients often complained marked stooped and leaned forward after a period of activity, 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), degenerative flat back syndrome, drop body syndrome.[21]

Takemitsu *et al.* first introduced "lumbar degenerative kyphosis", which included a marked decreased lumbar lordosis even lumbar kyphosis caused by degenerative changes in elderly people, and Takemitsu classified LDK into four types according to the sequence of the spine.[22,23] Degenerative flat back syndrome is a subtype of ASD which is rare in western countries. In western countries, it usually caused by iatrogenic factors, such as Harrington rod system surgery. But in Asian countries it is one of the common spinal deformities.[24,25] Zhou XH *et al.* recently characterized DSI as normal SVA ($SVA < 40\text{mm}$) at initiation, and prominent increase in SVA ($SVA \geq 40\text{mm}$) after activity with thunks marked inclined, and firstly proposed a quantitative diagnostic criteria and novel classification of DSI.[26]

Paravertebral muscle has long been viewed an important factor in the stabilization of spinal sequence. Among them, erector spinae and multifidus play important roles in the extension of the spine in reaction to gravity and body weight to maintaining spinal balance.[4][11] Takemitsu *et al.* reported pathologic features of LDK as marked paravertebral muscle atrophy with adipose infiltration.[18,22] Although the exact pathophysiology of flat back has not yet been **explicitated**, extensive degeneration of lumbar extensor muscles are thought to be responsible for degenerative flat back syndrome in most patients. Drop Body syndrome described by Mitsuru *et al.* was a primary lumbar kyphosis without obvious coronal deformity, also accompanied with severe atrophy and fatty infiltration of the MF muscle.[21] However, there is no systematic study to explore the paravertebral muscles changes of dynamic sagittal imbalance.

The present study mainly aimed to explore the changes of paravertebral muscles in DSI patients, which would help spinal surgeons better understand the importance of paravertebral muscles in maintaining the balance of spine.

Methods

Demographic characteristics

470 *outpatients and inpatients* at the Department of Spine of the authors' facility from March 2018 to May 2020 were recruited. All participants were asked to fill in the *form 1*. For a primary diagnosis of DSI, the patient must meet one major criterion and/or more than one minor criterion. After that, all subjects

underwent radiologic whole spine X-ray examination in the natural standing position. Patients with pre-walk sagittal vertical axis (SVA) ≥ 40 mm on imaging were excluded .[12]

Then these participants who met the primary diagnosis were asked to participate a 10-minute walk experiment at their usual speed, in order to verify that symptoms of DSI do exist. They were asked to wear tight clothing for easy observation. Dynamic posture images of the entire walk test was obtained using a high-resolution camera , which was placed on a tripod at hip-height. Two well-trained spine surgeon would supervise each participant for the entirety of the 10-min walk experiment. Marker points were defined at anatomic landmarks (C7 and junction of hip), trunk inclination angle (INC) refers to the angle of the junction of hip and C7 marker from the vertical.[32] After that, two well-trained spine surgeon would measure these dynamic posture images , once the participant's trunk incline (INC $\geq 10^\circ$), the point-in-time was recorded. The trunk inclination needed to be confirmed DSI by two spine surgeon together. Point-in-time was assessed twice by two independent spinal surgeons , and the average value was calculated as the final result. *Finally, the total of 31 patients was included as the DSI groups.* DSI patients could be classified into five subgroups based on the point-in-time: $0 \leq \text{time} < 2 \text{ min}$, $2 \leq \text{time} < 4 \text{ min}$, $4 \leq \text{time} < 6 \text{ min}$, $6 \leq \text{time} < 8 \text{ min}$, $8 \leq \text{time} < 10 \text{ min}$.

The exclusion criteria were: spondylolysis/spondylolisthesis, congenital or neuromuscular scoliosis, post-traumatic kyphosis, severe low back pain (NRS score > 3) , a hip joint or pelvic disease, compression fracture, symptomatic lumbar stenosis, structural kyphosis and Cobb angle $> 30^\circ$. .

. Among the remaining 439 participants , the enrollment criteria of *control* group include : no *history of* chronic low back pain (NRS score > 3) or a history of spinal surgery. To reduce bias because of obesity and age, the participants were matched with the DSI patients on the basis of body mass index (BMI) and age . *Finally, A total of 42 people were selected for the control group. Moreover, Numeric Rating Scales (NRS, 0–10) for back pain and Oswestry Disability Index (ODI) scores were routinely collected.* 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 at initiation. Spinal-pelvic parameters such as pre-walk sagittal vertical axis (pre-walk 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 .MRI was performed using 1.5T Magnetom Vision (Magnetom Symphony; Siemens, Berlin, Germany) scanners. Five T2-weighted 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 [3,13], the muscle fat infiltration (FI) area was estimated using the subcutaneous fat threshold as the standard. 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), divided the FCSA of each muscle by the CSA of the upper endplate of L5. [13] 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.

All data was assessed twice by two independent spinal surgeons, and the average value was calculated as the final result.

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 fat infiltration between the DSI group and control group. The correlation between paravertebral muscle changes and point-in-time of occurrence of dynamic sagittal imbalance was analyzed by Spearman correlation coefficient, and simple linear regressions were simultaneously conducted. All data were presented as mean values \pm SEM (standard error of the mean). P-value < 0.05 was considered to be statistically significant.

Results

Demographic data The DSI group comprised 3 men and 28 women (age, 63.7 ± 4.8 yo; height, 159.8 ± 6.3 cm; and BMI, 25.0 ± 3.3). The control group comprised 2 men and 40 women (age, 63.5 ± 4.1 yo; height, 158.3 ± 6.4 cm; and BMI, 23.9 ± 3.4). There were no significant differences in age, body weight, height, or BMI between the 2 groups. Moreover, there were no significant differences in NRS for low back pain between the two groups. (Table 1). As for ODI scores, we can find statistical differences between the two groups, DSI group had higher scores (29.7 ± 4.6) compared with control group (24.7 ± 6.9). 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 ± 24.1) had a lower LL than the control group (ranging from -55.6 to 21.7, -22.4 ± 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) Definition of threshold values of DSI Total 32 DSI patients could be classified into five subgroups based on the point-in-time once the participant's trunk incline in 10-minute walk experiment: $0 \leq \text{time} < 2 \text{min}$ $2 \leq \text{time} < 4 \text{min}$ $4 \leq \text{time} < 6 \text{min}$ $6 \leq \text{time} < 8 \text{min}$ $8 \leq \text{time} < 10 \text{min}$. The proportions of each subgroup were separately 9.6%(3/31),38.7%(12/31),22.6%(7/31),16.1%(5/31), 12.9%(4/31). Additionally, the correlations between the point-in-time of occurrence of dynamic sagittal imbalance and paravertebral muscle changes are summarized in Table 6, and the regression models employed are displayed in Fig.2. At L4/L5 level, the authors found that the point-in-time of occurrence of dynamic sagittal imbalance was statistically correlated with the relative total cross-sectional area of ES and MF($r_s = 0.783, P < 0.001$; $r_s = 0.683, P < 0.001$), the relative functional cross-sectional area of ES and MF ($r_s = 0.899, P < 0.001$; $r_s = 0.487, P = 0.005$), the fat infiltration of ES($r_s = -0.370, P = 0.041$). Whereas, the point-in-time of occurrence of dynamic sagittal imbalance had no statistically correlated with the fat infiltration of MF ($r_s = -0.020, P = 0.913$). But at L2/L3 level, the authors found no correlation between the point-in-time of occurrence of dynamic sagittal imbalance and muscles degeneration. The detailed results are displayed in Table 7.

Discussion

Sagittal balance is a primary issue for clinical assessment of spine.[1]The value of SVA has obvious correlation with HRQOL(Health related quality of life).The larger the C7-SVA, the worse the HRQOL. [2]Sagittal imbalance have always been a concern for spinal surgeons,restoring normal spinal balance is particularly important in the treatment of spinal disorders.[27]Paravertebral muscles have long been considered playing important roles in maintaining spinal stability.[11]Among these paravertebral muscles, erector spinae and multifidus got more attention for their function.Their functions are the extension of the spine in reaction to gravity and body weight as well as the maintenance of lumbar spine stability,the degeneration of paravertebral muscle may cause instability of the spine.[28]In previous study paravertebral muscle changes in different spinal disorders have been extensively studied.[8-10]However, there is no systematic study to explore the paravertebral muscles changes of dynamic sagittal imbalance.

Recently,in Zhou's innovative study, 133 adult spinal deformity patients with stooping and back pain after walking were retrospectively analyzed,he also proposed a quantitative diagnostic criteria and novel classification of DSI.[26]Different from Zhou's study,in present study,any subjects with low back pain (NRS ≥ 3)was excluded,in order to minimize the interference of low back pain to the sagittal imbalance.In previous studies,Paul et al. had confirmed the decreased lumbar stability in low back pain(LBP) patients,which may lead to sagittal imbalance. [5]In our previous study, we also demonstrated that severe LBP due to lumbar disc herniation can lead to sagittal imbalance in some patients.[6]Therefore, we can't overlook the roles of LBP in sagittal balance.

Moreover,we found that DSI patients had decreased lumbar lordosis compared with patients in control group.Previous studies have demonstrated decreased lumbar lordosis and lumbar kyphosis could cause SVA changes,a decreased lumbar lordosis or lumbar kyphosis is positively correlated with increased SVA.

[4][7] Many factors may contribute to decreased lumbar lordosis. However, in this cross-sectional study, it was hard to explore the cause of the reduction in lumbar lordosis, which may require a long-term longitudinal study.

Paravertebral muscle degeneration is characterized by a decrease of muscle size and infiltration of fat tissue, these features predict the deterioration of muscle function. [5][6] In previous study, Shahidi et al. found there was an increase in fatty infiltration with age in erector and multifidus muscles [29] Fortin *et al.* conducted a longitudinal study on magnetic resonance imaging of MF muscle for more than 15 years and found that muscle fat infiltration was significantly correlated with body mass index (BMI). [33] Thus, in present study, the control participants were matched with the DSI patients on BMI and age.

As we all know, anterior translation of the gravity line would lead to the fatigue of back extensor muscles, which further accelerates sagittal imbalance [28][30]. Therefore, in our study, patients with pre-walk SVA \geq 40mm on imaging were excluded there was no statistically significant differences in SVA at initiation between the two above groups. We minimized the disturbance of SVA at initiation to the sagittal imbalance, in order to explore the influence of paravertebral muscle on DSI only.

From our study, we found that DSI patients had more severe fat infiltration of paravertebral muscles compared with patients in control group. In previous study [28], Jun et al. noticed that muscle-strengthening exercises could serve to maintain the quality of spinopelvic muscles and thus prevent spinal sagittal imbalance. In Zhou's recent study, they also speculated that the weakening of paraspinal muscles leads to the occurrence of dynamic sagittal imbalance. Thus in our opinion, because the degeneration of paravertebral muscles is more severe in DSI patients compared with control participants,

there were marked differences identified at same spinal sequence between the DSI group and control group, with DSI consistently worse with poorer paravertebral muscle function and more prone to fatigue. That's why DSI patients got stooped during the 10-minute walk test. **(Fig. 3)** Lower extremities-related compensatory mechanisms sagittal imbalance is complicated, included the flexion of knees as well as extension of the hips and ankles. [31] Left the effect of lower extremities not considered, at initiation before the 10-minute walk test, paravertebral muscles in DSI patients were sufficient to keep sagittal balance. However, during 10-min walk test, paravertebral muscles get fatigue quickly for reduced endurance and strength of paravertebral muscles. Whereas in control group, paravertebral muscles are strong enough to keep sagittal balance during 10-min walk test.

Furthermore, we found the point-in-time of occurrence of dynamic sagittal imbalance was statistically correlated with degeneration of paravertebral muscles at L4/L5 level, whereas no correlation between the two above at L2/L3 level. It was a novel finding that lower lumbar paravertebral muscles play important roles in maintaining spinal balance compared with upper paravertebral muscles. Xia [10] studied the association between paravertebral muscles and spinal-pelvic parameters in patients with LDK, they found the fat infiltration and atrophy of erector spinae at the lower lumbar level would affect the pelvic parameters, which may lead to spinal sagittal imbalance. The PDSI (Primary degenerative sagittal imbalance) concept has been proposed recently by Chang-hyun Lee, fixed sagittal imbalance (SVA \geq 4cm at

initiation) with severe paravertebral muscles degeneration.[17]Therefore, We conjecture that DSI is the pre-state of PDSI.In DSI patients, although the paravertebral muscles had degenerated to an extent, they could still maintain spinal balance during short periods of activity.Whereas in PDSI patients,as the paravertebral muscles degenerate further, even at the time of motionless standing,they would get fatigue quickly and are unable to maintain sagittal balance.

The present study had some limitations that need further discussion and investigation.First, an inherent limitation of this study is the sample size, which might lead to selection bias.Future work will collect a larger sample to explore the detailed characteristics of DSI patients.Second,because most of the participants were outpatients, we did not use the gait analysis or take post-walk full-spine X-ray photograph to get more detailed differences between pre-walk and post-walk ,because it was inconvenient in the busy outpatients.Third, it is relatively hard to apply our conclusions to relatively young patients,because the average age in the present paper is 63.7 ± 4.8 years.Future work will collect a larger sample to establish baseline values for the change in DSI patients in different age groups and gender groups.Fourth, the compensatory mechanisms of lower extremities has not been taken into account in this study. Full-body radiographs are needed to evaluate the effect of lower limbs in further plan.Fifth, in this cross-sectional study,it is hard to expolre its dynamics of DSI,loneger follow-up of these DSI patients should be collect to explore dynamic change the of DSI.

Conclusions

In conclusion,DSI an normal SVA ($SVA < 40\text{mm}$) at initiation,and prominent increase in SVA ($SVA \geq 40\text{mm}$) after activity with thunks marked inclined.Paravertebral muscle degeneration plays an important role in the DSI process,Patients in the DSI group had more severe paravertebral muscle degeneration compared with patients in control group.There was a significant correlation between the severity of DSI symptoms and the degeneration of lower lumbar paravertebral muscles. These findings may help spinal surgeons better understand sagittal balance of spine.

Abbreviations

SVA, sagittal vertical axis;DSI,dynamic sagittal imbalance;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;FI,fat infiltration;RCSA,relative cross-sectional area;RFCSA,relative functional cross-sectional area;LDK,degenerative lumbar kyphosis;INC,trunk inclination angle;NRS,*Numeric Rating Scales*;ODI,*Oswestry Disability Index*;ROI,regions of interest;RTCSA,relative total cross-sectional area;LBP,low back pain;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 First Medical University

Consent for publication The images appearing in Figs. 1–3 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 and GW thought out the study, participated in its design and coordination. NR carried out this study, did the statistics and drafted the manuscript. 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 Resnet Framework. *J Clin Med*, 2019 Nov 1;8(11):1826.
- [2] Mac-Thiong JM, Transfeldt EE, Mehbood 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] 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.
- [6] 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.

- [7]Jang JS, Lee SH, Min JH, *et al.* Lumbar degenerative kyphosis: radiologic analysis and classifications. [J]. Spine, 2007, 32(24):2694-2699.
- [8]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.
- [9]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.
- [10]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).
- [11]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.
- [12]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.
- [13]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).
- [14]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.
- [15]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.
- [16]Mazel C , Ajavon L . Malunion of post-traumatic thoracolumbar fractures[J]. Retour Au Numéro, 2018, 104(1S).
- [17]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.
- [18] Vialle, Rapha?l. 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.
- [19]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.

- [20]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.
- [21]Yagi M , Kaneko S , Yato Y , *et al.* Drop Body Syndrome -A distinct form of adult spinal deformity[J]. Spine, 2017, 42(16):E969.
- [22]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
- [23]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.
- [24]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.
- [25] Potter BK, Lenke LG, Kuklo TR. Prevention and management of iatrogenic flatback deformity. [J].Journal of Bone & Joint.2004;86(8):1793-1808.
- [26]Yin J, Ma X, Lin T, Gao R, Zhou X. Characteristics and treatment of dynamic sagittal imbalance in adult spinal deformity. *Eur Spine J.* 2020;29(9):2340-2353.
- [27]Lee CH, Chung CK, Jang JS et al (2017) Effectiveness of deformity-correction surgery for primary degenerative sagittal imbalance: a meta-analysis. J Neurosurg Spine 27(5):540– 551
- [28]Jun HS, Kim JH, Ahn JH, Chang IB, Song JH, Kim TH, Park MS, Chan Kim Y, Kim SW, Oh JK, Yoon DH (2016) The effect of lumbar spinal muscle on spinal sagittal alignment: evaluating muscle quantity and quality. Neurosurgery 79:847–855.
- [29]Shahidi B, Parra CL, Berry DB, Hubbard JC, Gombatto S, Zlomislic V, Allen RT, Hughes-Austin J, Garfin S, Ward SR (2017) Contribution of lumbar spine pathology and age to paraspinal muscle size and fatty infiltration. Spine (Phila Pa 1976) 42:616– 623.
- [30] Banno T, Yamato Y, Hasegawa T, Kobayashi S, Togawa D, Oe S, Mihara Y, Kurosu K, Yamamoto N, Matsuyama Y (2017) Assessment of the cross-sectional areas of the psoas major and multifidus muscles in patients with adult spinal deformity: a case-control study. Clin Spine Surg 30:E968–E973.
- [31]Barrey C, Roussouly P, Le Huec JC, D’Acunzi G, Perrin G (2013) Compensatory mechanisms contributing to keep the sagittal balance of the spine. Eur Spine J 22(Suppl 6):S834–841.
- [32]Ludwig O . Interrelationship between postural balance and body posture in children and adolescents[J]. Journal of Physical Therapy ence, 2017, 29(7):1154-1158.

[33]Fortin M, Videman T, Gibbons LE, Battié MC. Paraspinal muscle morphology and composition: a 15-yr longitudinal magnetic resonance imaging study. *Med Sci Sports Exerc.* 2014;46(5):893-901.

Tables

TABLE 1. The primary 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, and more likely to carry heavy objects on back?	YES/NO
	4. Support with elbows in order to wash dishes or face?	YES/NO

For a primary 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

	DSI (n=31)	Controls (n=42)	P
Age(y)	63.7±4.8	4.1	0.545
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
NRS for back pain	2.6±0.7	2.7±0.6	0.342
ODI	29.7±4.6	24.7±6.9	0.002*

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

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

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

	DSI (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
pre-walkSVA(cm)	1.4±4.0	1.7±3.7	0.639

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

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	$\leq 0.001^*$
	ES	30.6±9.6	20.8±17.4	0.023*
L4/L5(%)	MF	49.6±12.3	26.6±14.2	$\leq 0.001^*$
	ES	34.4±7.4	20.6±13.2	$\leq 0.001^*$

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;*Statistical significance.

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

Table 6. Correlations between paravertebral muscles parameters at L4/L5 level and the point-in-time once the participant's trunk incline

Muscles parameters(L4/L5)	Correlation coefficient	P
MF FI	-0.020	0.913
ES FI	-0.370	0.041*
MF RFCSA	0.487	0.005*
ES RFCSA	0.899	∅0.001*
MF RTCSA	0.683	∅0.001*
ES RTCSA	0.783	∅0.001*

ES, indicates erector spinae; MF, multifidus; FI,fat infiltration

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

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

Table 7. Correlations between paravertebral muscles parameters at L2/L3 level and the point-in-time once the participant's trunk incline

Muscles parameters(L2/L3)	Correlation coefficient	P
MF FI	0.17	0.360
ES FI	0.12	0.535
MF RFCSA	0.13	0.480
ES RFCSA	0.27	0.887
MF RTCSA	0.241	0.192
ES RTCSA	0.137	0.464

ES, indicates erector spinae; MF, multifidus; FI, fat infiltration

RTCSEA , Relative total cross-sectional area; RFCSEA ,Relative functional cross-sectional area

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

Figures

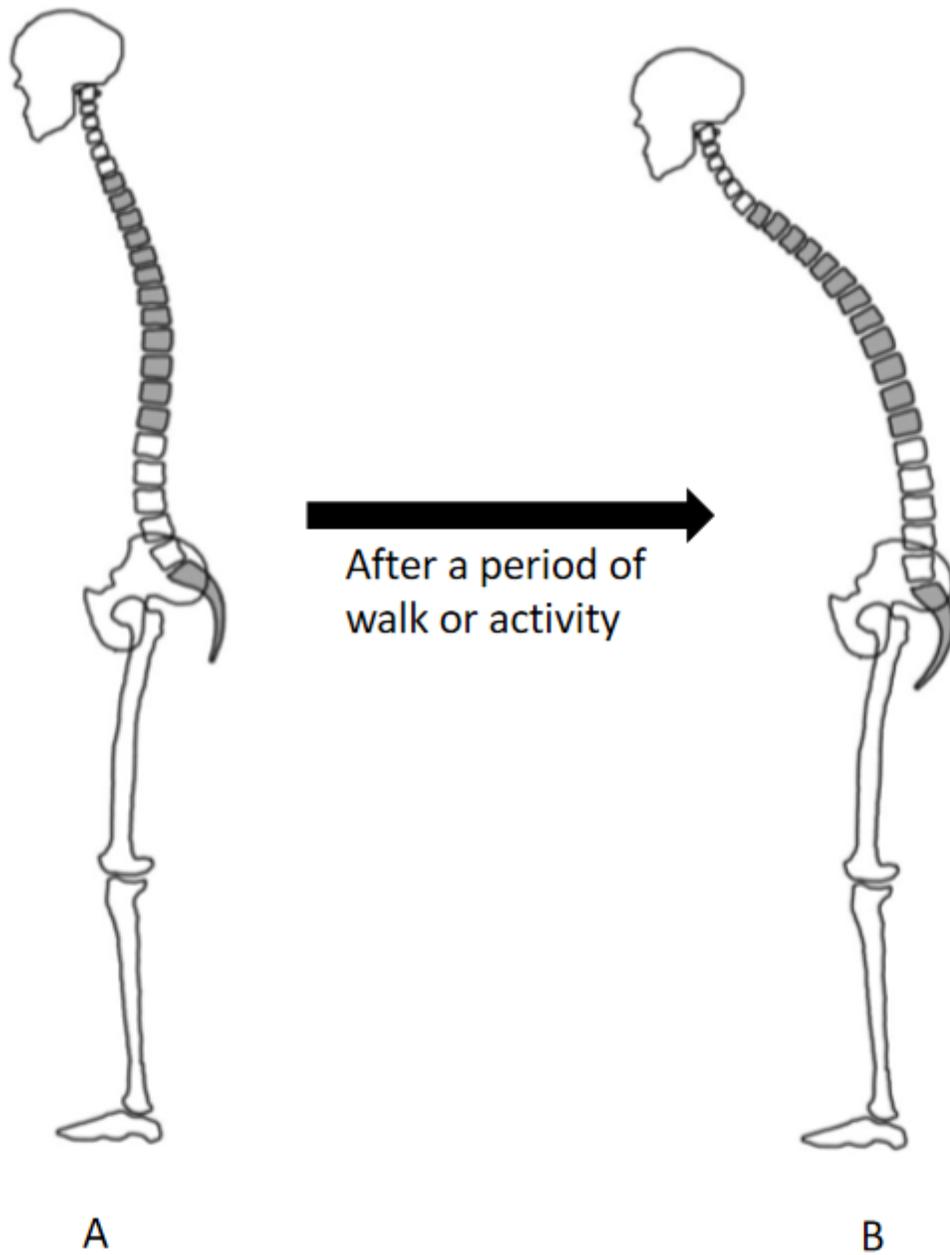


Figure 1

A: At initiation, patients with DSI generally show normal sagittal balance. B :After a period of walk or activity, patients with DSI would show sagittal imbalance.

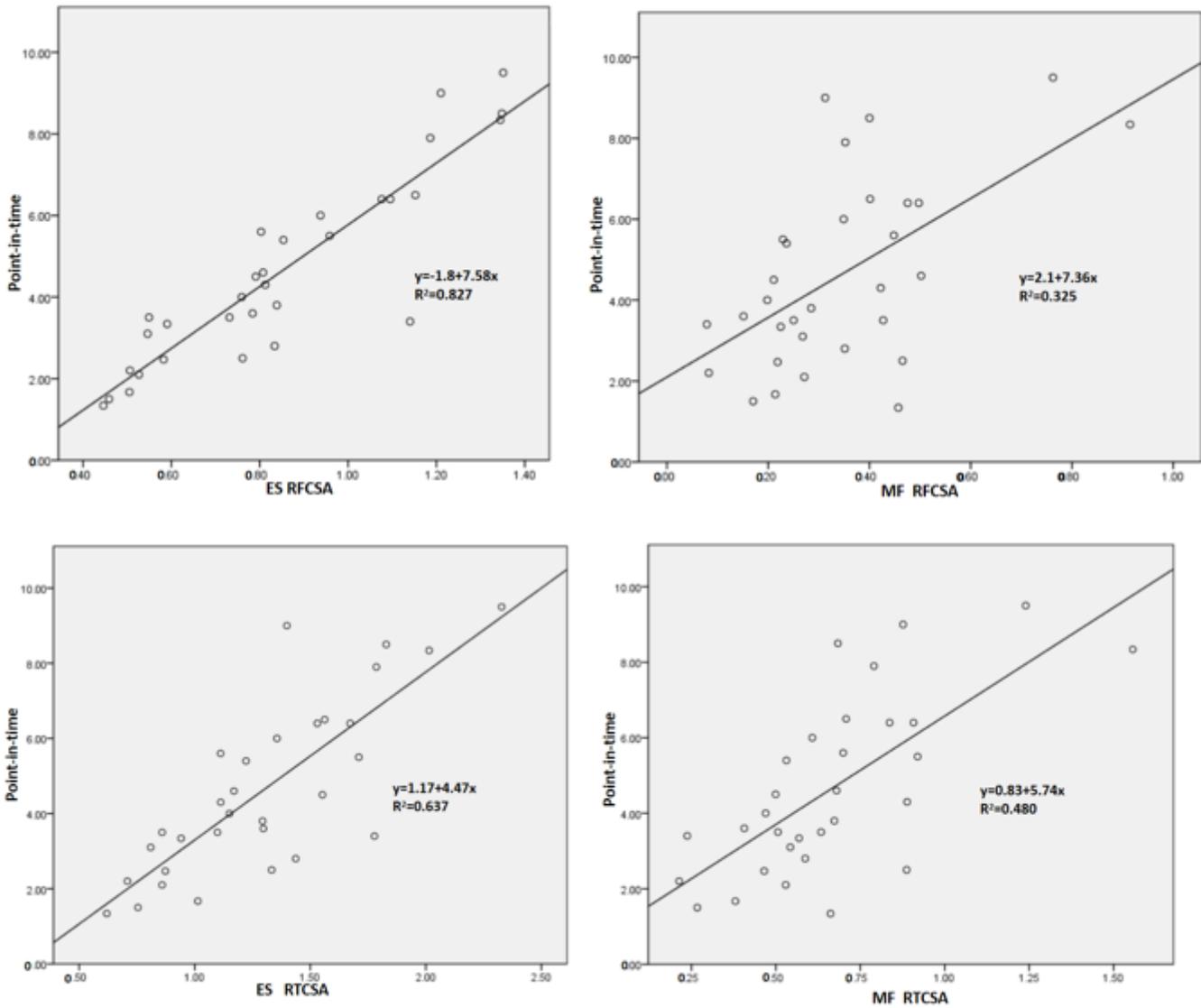


Figure 2

Linear regression between the point-in-time of occurrence of dynamic sagittal imbalance and paravertebral muscles parameters. ES, indicates erector spinae; MF, multifidus; RTCSA , Relative total cross-sectional area; RFCSA ,Relative functional cross-sectional area

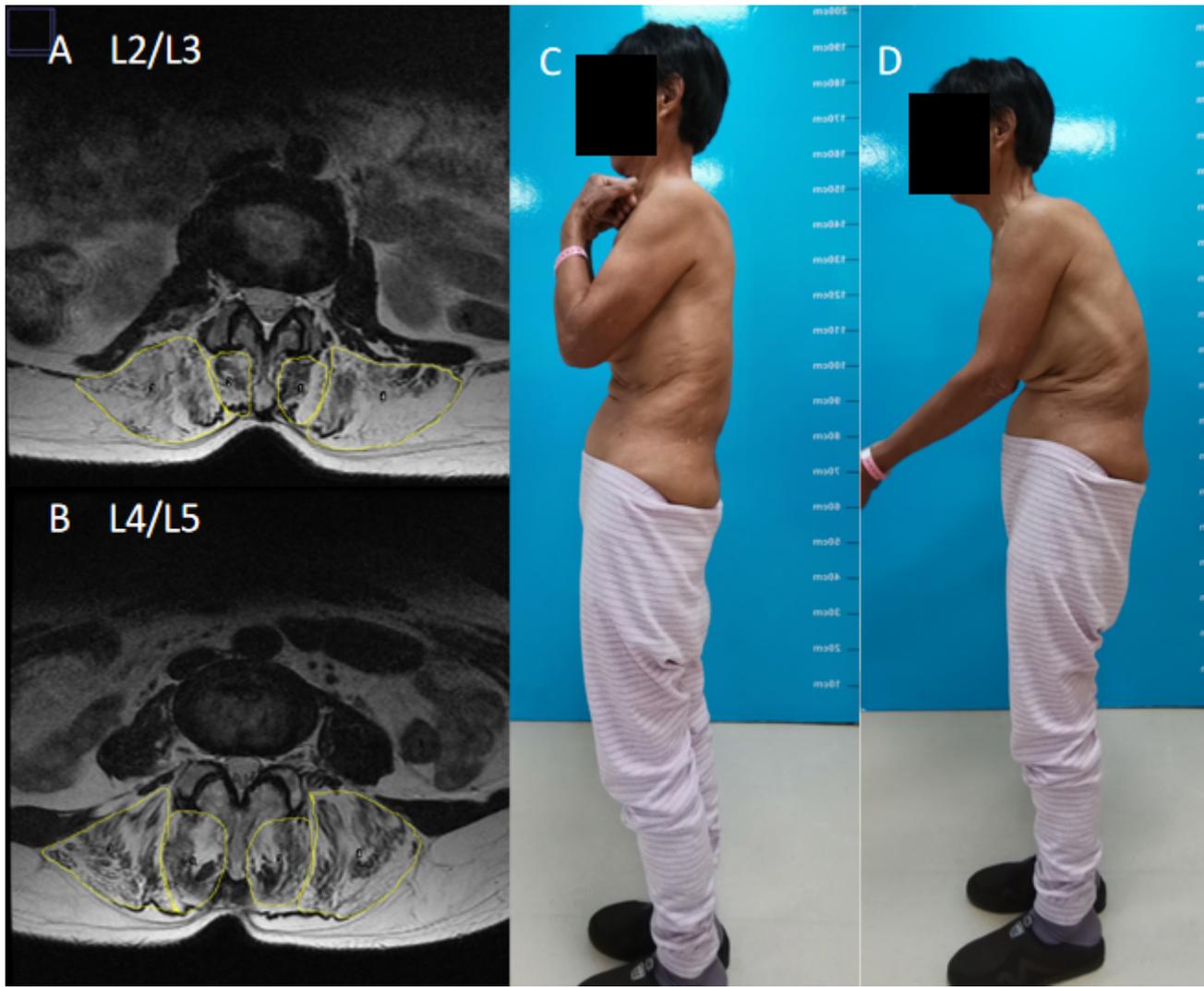


Figure 3

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