

Clinical Study

# Changes of balance control in individuals with lumbar degenerative spine disease after lumbar surgery: a longitudinal study

Wei-Jin Wong, PT<sup>a,#</sup>, Dar-Ming Lai, MD, PhD<sup>b,#</sup>,  
Shwu-Fen Wang, PT, PhD<sup>a,c</sup>, Jaw-Lin Wang, PhD<sup>d</sup>, Wei-Li Hsu, PT, PhD<sup>a,c,\*</sup>

<sup>a</sup> School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, Taipei, Taiwan

<sup>b</sup> Division of Neurosurgery, Department of Surgery, National Taiwan University Hospital, Taipei, Taiwan

<sup>c</sup> Physical Therapy Center, National Taiwan University Hospital, Taipei, Taiwan

<sup>d</sup> Department of Biomedical Engineering, National Taiwan University, Taipei, Taiwan

Received 27 November 2018; revised 24 February 2019; accepted 27 February 2019

## Abstract

**BACKGROUND CONTEXT:** Lumbar degenerative spine disease (DSD) with neurological symptoms is the most common indication requiring lumbar surgery when nonoperative treatment is not effective. Individuals with lumbar DSD have sensory, proprioception, and musculoskeletal system alterations, which may result in balance impairment. However, evidence regarding balance recovery in individuals with lumbar DSD after lumbar surgery is limited.

**PURPOSE:** To evaluate balance control, pain, and functional activities in individuals with lumbar DSD after lumbar surgery.

**STUDY DESIGN/SETTING:** A prospective study with a cross-sectional control group.

**PATIENT SAMPLE:** Seventy individuals with lumbar DSD (DSD group) and 30 age-matched healthy adults (control group) were recruited. Participants in the DSD group were diagnosed by a neurological surgeon and received lumbar surgery according to relevant imaging findings and neurological symptoms.

**OUTCOME MEASURES:** Clinical assessments, including a visual analogue scale (VAS), the Oswestry Disability Index (ODI), and the Roland-Morris Disability Questionnaire (RMDQ), were performed in the DSD group only. Balance control was assessed in all participants using the root mean square (RMS) distance of the center of pressure (COP) in anteroposterior and mediolateral directions.

**METHODS:** All participants were instructed to stand in natural stance and Romberg stance with eyes open and eyes closed on a force platform for 35 seconds, respectively. The assessments were performed in the DSD group at four time points: preoperative phase (baseline), 3 months, 6 months, and 12 months postoperatively. In the age-matched healthy control group, only one assessment on the recruitment day was performed.

**RESULTS:** The VAS, ODI, and RMDQ scores of the DSD group significantly improved after lumbar surgery ( $p < .001$ ). The RMS distance of COP in the DSD group significantly decreased after lumbar surgery ( $p < .017$ ) compared with baseline in most of the testing conditions. However, the RMS distance of the COP in the DSD group after surgery was significantly greater than in the healthy control group ( $p < .05$ ), especially 6 months and 12 months postoperatively.

**CONCLUSIONS:** Balance control, pain, and functional activities of individuals with lumbar DSD showed improvement after lumbar surgery. However, balance control in individuals with lumbar

FDA device/drug status: Not applicable.

Author disclosures: **W-JW:** Nothing to disclose. **D-ML:** Nothing to disclose. **S-FW:** Nothing to disclose. **J-LW:** Nothing to disclose. **W-LH:** Grants: National Health Research Institutes (H [New Taiwan Dollar], paid directly to institution), Ministry of Science and Technology (I [New Taiwan Dollar], paid directly to institution), National Taiwan University (G [New Taiwan Dollar], paid directly to institution).

\* Corresponding author. School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, Room326, Floor 3, No.17, Xuzhou Rd., Zhongzheng District, Taipei City 100, Taiwan. Tel.: 886-2-3366-8127.

E-mail address: [wlhsu@ntu.edu.tw](mailto:wlhsu@ntu.edu.tw) (W.-L. Hsu).

# These authors have equally contributed to this study.

DSD was still less stable than in age-matched healthy adults from 6 to 12 months after surgery. Therefore, individuals with lumbar DSD require fall prevention programs after lumbar surgery, including balance assessments and postoperative balance training. © 2019 Elsevier Inc. All rights reserved.

**Keywords:** Biomechanics; Balance control; Center of pressure (COP); Functional assessment; Lumbar degenerative spine disease (DSD); Lumbar surgery

## Introduction

Lumbar degenerative spine disease (DSD) has a high prevalence and common among older adults [1]. Degeneration of the lumbar spine includes conditions such as spinal stenosis, spondylolisthesis, and disc degeneration, which may cause compression or inflammation on spinal nerve root [2]. Individuals with lumbar DSD may be associated with a variety of clinical symptoms, such as low back pain, altered sensation in the lower extremities, weakness, and neurogenic claudication. Symptomatic lumbar DSD may not only lead to decreased walking capacity and functional activities, but also impact balance performance [3–5]. Changes of sensation and proprioception inputs in the lumbar spine and lower extremities, resulted from lumbar nerve root compression, have been associated with balance control impairment in individuals with lumbar DSD [6–8]. In addition, spinal deformity, trunk muscle weakness, and delayed neuromuscular recruitment of the deep trunk muscles may lead to balance instability [9,10]. Previous studies showed individuals with lumbar DSD demonstrate increased center of pressure (COP) sway during quiet standing compared with healthy adults, indicating individuals with lumbar DSD have unstable balance control [7,11,12]. Therefore, balance assessments are important in individuals with lumbar DSD.

Lumbar surgery has been widely used to alleviate pain and neurological symptoms of individuals with lumbar DSD [13]. Although conservative treatments, such as physical therapy and medications, are considered initially; lumbar surgery is an option when conservative treatments are not effective [14–16]. The concept of lumbar surgery is to remove the sources of the compression and irritation. Several studies have reported the immediate effects of lumbar surgery for pain improvement and recovery of daily functional activities in individuals with lumbar DSD [17–21]. However, few studies have indicated changes in standing balance performance after lumbar surgery [7,22–24]. Moreover, joint restriction may limit the ability of joint coordination, and could cause balance stability [25]. It remains unclear whether balance control during quiet standing is recovered after lumbar surgery, especially in the late postoperative phase. Therefore, this study investigated changes in balance control during quiet standing, as well as changes in pain and functional activities, in individuals with lumbar DSD after lumbar surgery and compared them with age-matched healthy adults. The research hypothesis

was that balance control, pain, and functional activities of individuals with lumbar DSD would be improved after lumbar surgery but that the individuals with lumbar DSD would still have unstable balance control compared with age-matched healthy adults.

## Material and methods

### Study design

This longitudinal clinical study was designed to determine the progression of static balance performance and functional outcomes in individuals with lumbar DSD 3 months, 6 months, and 1 year after lumbar surgery. This research adhered to the principles of the Declaration of Helsinki for human research. This study was approved by the Research Ethics Committee of National Taiwan University Hospital (IRB reference number 201112117RIC) and registered with ClinicalTrials.gov (identifier NCT01703338).

### Study procedure

The flowchart of this study is shown in Fig. 1. Participants in the lumbar DSD group (DSD group) and age-matched healthy control group were assessed for eligibility. Recruited participants were provided an explanation of the study and the written informed consent at the Department of Surgery, National Taiwan University Hospital. For the DSD group, data collection included demographic data, anthropometric data, functional assessments, and standing balance assessment. The data collections for the DSD group were initiated before lumbar surgery and were repeated at 3 months, 6 months, and 12 months postoperatively as follow-up. For the age-matched healthy control group, the same data collection procedure was applied, except for pain and functional assessments. Data were collected in the clinic at the Department of Surgery, National Taiwan University Hospital.

### Participants

Seventy individuals with lumbar DSD were recruited. The study included individuals with lumbar DSD who were diagnosed by a neurological surgeon and received lumbar surgery according to relevant imaging findings and neurological symptoms. The participants of the DSD group had to meet the following inclusion criteria: (1) aged between 20 and 85 years; (2) a primary diagnosis of lumbar DSD

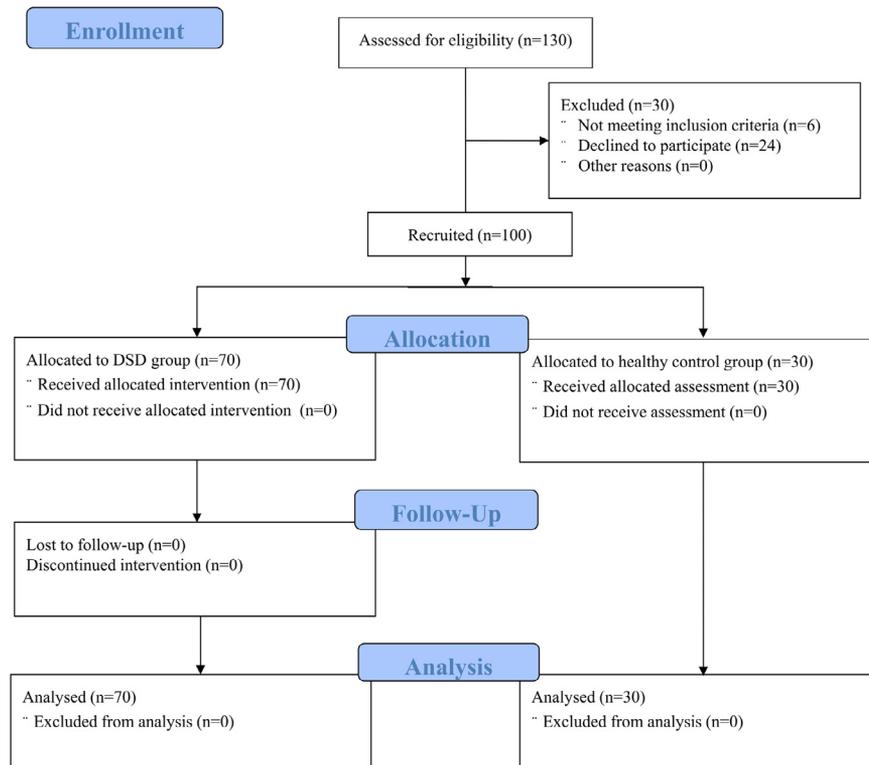


Fig. 1. Flowchart of participant recruitment.

with neurological symptoms due to nerve root compression, (3) radiculopathy exceeding 12 weeks for which conservative treatment had failed to make improvements; and (4) selection for lumbar surgery. Exclusion criteria were as follows: (1) mechanical back pain owing to postural changes and inability to maintain an upright posture for over 30 minutes; (2) segmental instability including isthmic spondylolisthesis and degenerative spondylolisthesis greater than 0.4 cm; (3) intervertebral angle reversal on dynamic radiographs; (4) idiopathic scoliosis greater than 30°; and (5) previous lumbar surgery, rheumatoid arthritis, or ankylosing spondylitis.

Thirty age-matched healthy controls were recruited. The participants in the control group were eligible for participation if they had no neck or back pain, severe musculoskeletal injury of the lower extremities or spine, vestibular dysfunction, or neurological dysfunction. Exclusion criteria for the control group were the same as that for the DSD group.

### Study measures

#### Pain intensity

The pain assessment was conducted in the DSD group only. The severity of pain was self-assessed in the DSD group using a 0- to 100-mm visual analogue scale (VAS). Higher scores indicated greater intensity (0 = no pain, 100 = worst pain imaginable). The VAS is considered a tool with high validity (95% confidence interval, 0.96–0.98) for

evaluating acute pain [26] and is commonly used in orthopedic clinics [27]. The magnitude of effect (small, moderate, or large) on the VAS was determined as described in a clinical practice guideline issued by the American College of Physicians [15]. A mean difference of 5 to 10 points was identified as a small effect on pain, whereas a mean difference of >10 to no more than 20 points was defined as a moderate effect. A mean difference of >20 points was defined as a large effect.

#### Functional assessment

Functional assessments were conducted in the DSD group only.

**Oswestry Disability Index.** The Oswestry Disability Index (ODI) was used to examine self-reported disability associated with low back pain. The ODI assesses 10 daily activities, including pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life (if applicable), social life, and travelling. Six statements rank the severity of symptoms from 0 to 5. Participants can assess their current status by choosing the most approximate statement. The result was represented in percentage, which was the sum of each item's score divided by the total possible score. Higher scores indicate greater disability in activities of daily living. The ODI demonstrates good validity and reliability in illustrating the recovery rate of individuals after lumbar surgery [28,29]. A minimal clinically important

difference (MCID) of 12.80 has been suggested in individuals after lumbar surgery [30].

**Roland-Morris Disability Questionnaire.** The Roland-Morris Disability Questionnaire (RMDQ) is a health status questionnaire that is self-completed by individuals to assess their physical disability resulted from low back pain. The questionnaire is a 24-item scale that consists of pain with social activities outside the house, sitting, walking, housework, going upstairs, lying down, resting, sit to stand, independence, dressing, turning over in bed, and nutrition. Each item can be checked if it applies to an individual for that day. A total score is obtained by counting the number of checked items. The total scores range from 0 (no disability) to 24 (severe disability). The test-retest reliability of RMDQ is 0.94 with a 95% confidence interval of 0.90 to 0.96 [29]. The construct validity has been proven in individuals after lumbar surgery. A change in score of 3.5 points has been shown to reflect an MCID [31].

#### Standing balance assessment

**Procedure of standing trial.** The standing balance assessment was conducted in the DSD group at four time points after surgery and in the age-matched healthy control group on the recruitment day. All participants were asked to stand barefoot on a force platform (Kistler 9286A; Kistler Instrument AG, Winterthur, Switzerland) for 35 seconds in each standing trial (Fig. 2). The participants performed the standing task with eyes open and eyes closed in two different foot positions. Overall, each participant performed four trials: natural stance (feet shoulder width apart) with eyes open and eyes closed, as well as Romberg stance (feet together) with eyes open and eyes closed. Feet

position was marked to ensure identical positioning for each trial. To avoid drifting of the COP signal, the force platform was calibrated for each trial before the data collection by resetting the unloaded force platform. Participants were allowed to rest if they felt tired or soreness in their legs.

**COP data processing.** Force platform signals were converted from analogue to digital at a sampling rate of 1000 Hz. LabVIEW software (National Instruments Corp., Austin, TX, USA) was used to compute the COP based on ground reaction force and moment in the anteroposterior (AP) and mediolateral (ML) directions. Then, the data were processed and filtered with a second-order Butterworth low-pass filter of 5 Hz by using MATLAB R2010a software (MathWorks, Natick, MA, USA). Data for 30 seconds in each trial were calculated and analyzed.

COP was further analyzed for time domain measures [32]. The root mean square (RMS) distance of COP was defined as the RMS value of the resultant distance time series. The resultant distance time series represents the vector distance from the mean COP to each pair of points in the AP and ML directions time series. A decrease in RMS distance represents an increased ability to preserve upright standing, whereas an increased value of RMS distance suggests a decreased ability to maintain balance control [33].

#### Statistical analysis

Descriptive data and results of the participants of the DSD group and the age-matched control group are presented as means  $\pm$  standard deviation. Statistical analysis was performed using PASW Statistics 18 for Windows software (SPSS, Chicago, IL, USA). The normality of data was determined according to their skewness and kurtosis and by using the Kolmogorov-Smirnov test. The comparison of demographic data between two groups was analyzed by independent samples *t* test or Mann-Whitney *U* test, depending on the normality. The majority of dependent variables was found to be not normally distributed or measured at the ordinal level (ie, RMDQ); thus, nonparametric statistics were used. A *p* value less than 0.05 (alpha,  $\alpha$ ) was considered statistically significant.

The DSD group was assessed at the 0-month preoperative phase (baseline) and at 3 months, 6 months, and 12 months postoperatively. The DSD within-group differences in COP variables, pain, and functional assessment were evaluated using the Friedman test. When data were significant ( $p < .05$ ), post hoc analysis with the Wilcoxon signed-rank test was conducted with a Bonferroni correction ( $\alpha/3$ ) applied, resulting in a significance level set at  $p < 0.017$ . Differences in COP variables between the DSD group and the age-matched healthy control group were analyzed by Mann-Whitney *U* test at four time points.

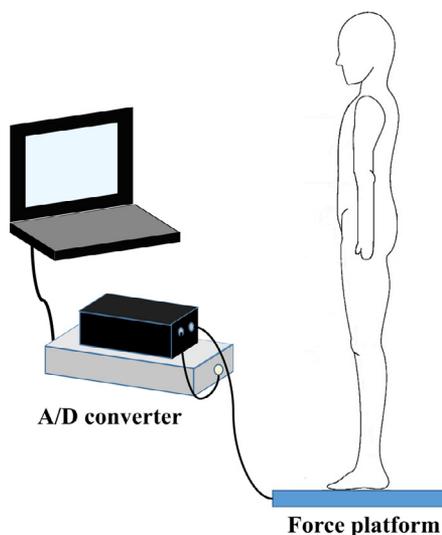


Fig. 2. Standing balance assessment setting.

## Results

A total of 100 participants were recruited into the study (DSD, n=70; control, n=30). Descriptive characteristics of the participants are summarized in [Table 1](#).

### Pain and functional assessments

[Table 2](#) shows changes in pain and functional assessments of the DSD group at all time points. Compared with baseline, the DSD group showed significant improvements in VAS, ODI, and RMDQ at 3 months, 6 months, and 12 months postoperatively ( $p < .001$ ), except for the RMDQ at 3 months ( $p = .018$ ) postoperatively. Compared with 3 months postoperatively, the DSD group also showed significant improvements in ODI and RMDQ at 6 months and 12 months postoperatively ( $p < .001$ ). However, no significant changes were found between 6 months and 12 months postoperatively.

The mean VAS score of the DSD group was 64.7 mm before surgery. After lumbar surgery, the mean VAS score of the DSD group decreased to less than 33.5 mm, a decrease of more than 30 mm, showing large effects. The mean ODI score of the DSD group decreased more than the MCID value of 12.80 after lumbar surgery compared with baseline. However, the mean RMDQ score only met the

MCID at 6 months and 12 months postoperatively compared with baseline.

### Standing balance assessment

Standing balance was assessed at the preoperative phase (baseline) and at 3 months, 6 months, and 12 months postoperatively. No serious falls occurred during data collection for all the participants. These results in different directions are described in the following subsections.

#### AP direction

[Fig. 3](#) displays the results of balance control in the AP direction during quiet standing. In natural stance, for the DSD within-group comparisons during eyes open, RMS distance of COP decreased significantly with mean difference  $0.40 \pm 0.09$  mm at 3 months ( $p = .015$ ) and  $0.54 \pm 0.36$  mm at 12 months ( $p = .003$ ) postoperatively compared with baseline, showing moderate effects ([Fig. 3A](#)). For the DSD within-group comparisons during eyes closed, RMS distance of COP decreased significantly by at least  $0.53 \pm 0.29$  mm at 3 months ( $p = .007$ ), 6 months ( $p = .011$ ), and 12 months ( $p = .001$ ) postoperatively compared with baseline, showing moderate to large effects ([Fig. 3B](#)). However, for the between-group comparisons, the results for the DSD group during eyes open and eyes closed were significantly greater than for the control group at all time points (all  $p < .05$ ; [Fig. 3A, B](#)). The mean differences of the results between two groups during eyes-open and eyes-closed conditions at all time points, ranged from  $0.55 \pm 0.27$  mm to  $1.35 \pm 0.93$  mm with moderate to large effects.

In Romberg stance, for the DSD within-group comparisons during eyes open, RMS distance of COP decreased significantly with mean difference  $0.39 \pm 0.15$  mm at 12 months ( $p = .016$ ) postoperatively compared with baseline. In the between-group comparisons during eyes open, RMS distance of COP in the DSD group was significantly greater than in the control group with mean difference  $0.80 \pm 0.19$  mm at baseline ( $p = .007$ ) only ([Fig. 3C](#)). For the DSD within-group comparisons during eyes closed, RMS distance of COP decreased significantly with mean difference  $0.64 \pm 0.46$  mm at 3 months ( $p = .015$ ) postoperatively

Table 1  
Demographics characteristics of participants

Characteristic	DSD group (n=70)	Control group (n=30)	p Value
Sex (male/female)	23/47	11/19	.70
Age (years)	62.1 ± 10.9	58.5 ± 7.7	.06
Height (cm)	157.8 ± 7.3	160.9 ± 7.0	.06
Weight (kg)	64.7 ± 13.2	64.9 ± 11.7	.53
BMI (kg/m <sup>2</sup> )*	25.8 ± 4.1	25.0 ± 3.9	.59
Surgical methods:			
(a) Decompression	15	NA <sup>†</sup>	
(b) Decompression with fusion	55	NA <sup>†</sup>	

Values are mean ± SD or number.

DSD, degenerative spine disease.

\* Body mass index.

<sup>†</sup> Not available.

Table 2  
Results of pain and functional assessment in DSD group

	0 month preoperatively	3 months postoperatively	6 months postoperatively	12 months postoperatively
VAS* (mm)	64.7 ± 23.7	33.5 ± 24.4 <sup>§</sup>	30.7 ± 25.8 <sup>§</sup>	28.5 ± 24.6 <sup>§</sup>
ODI <sup>†</sup> (%)	46.2 ± 15.1	28.9 ± 21.0 <sup>§</sup>	21.1 ± 17.2 <sup>§,  </sup>	19.8 ± 19.0 <sup>§,  </sup>
RMDQ <sup>‡</sup> (score)	12.3 ± 5.3	10.9 ± 5.2	7.9 ± 5.3 <sup>§,  </sup>	8.4 ± 6.0 <sup>§,  </sup>

Values are mean ± SD.

DSD, degenerative spine disease.

\* Visual analogue scale.

<sup>†</sup> Oswestry Disability Index.

<sup>‡</sup> Roland-Morris Disability Questionnaire.

<sup>§</sup>  $p < .001$  significant difference from 0 months preoperatively.

<sup>||</sup>  $p < .001$  significant difference from 3 months postoperatively.

### Root Mean Square Distance of COP in Anteroposterior Direction

 DSD group

 Control group

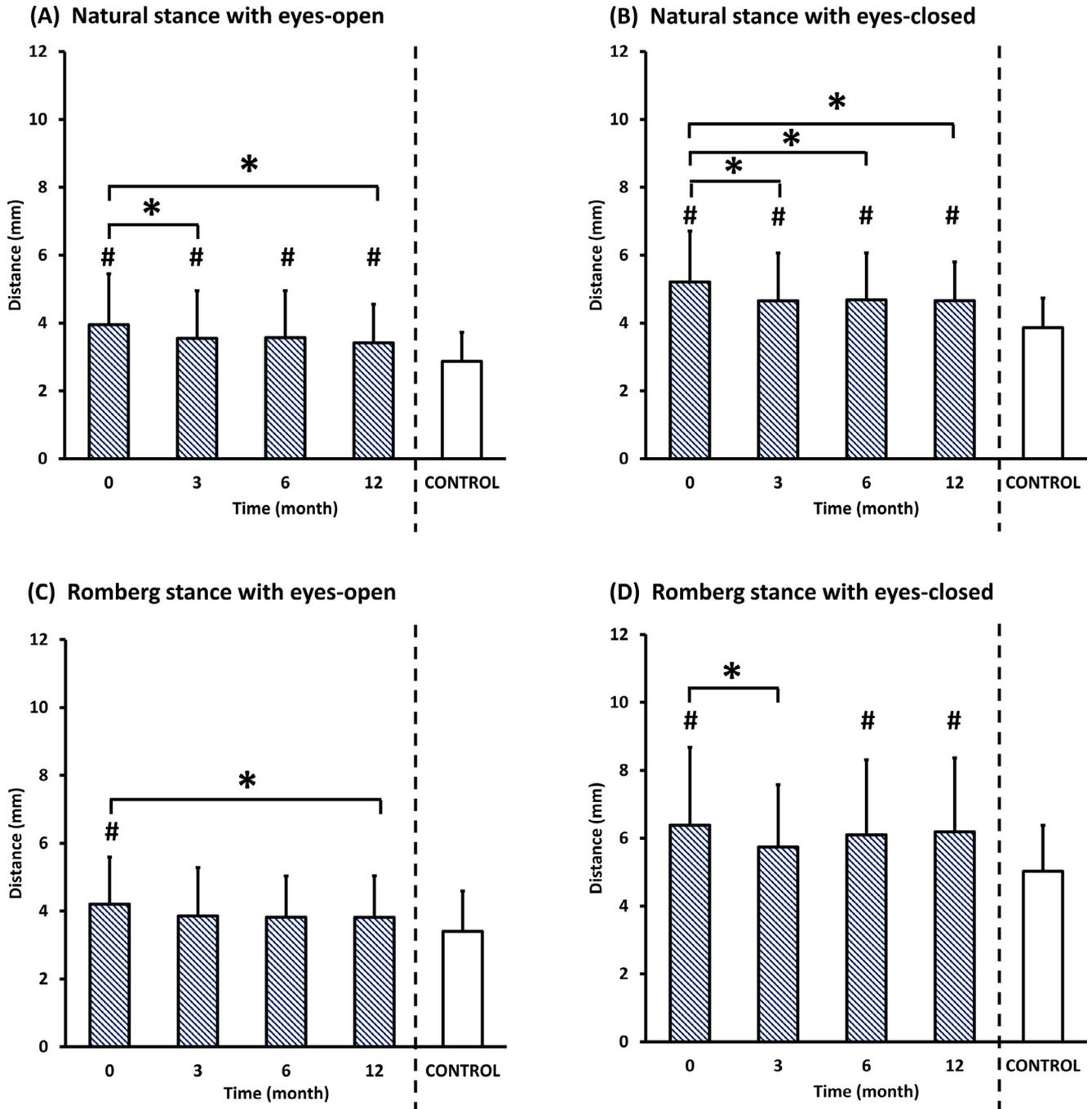


Fig. 3. Root mean square distance of center of pressure in anteroposterior direction. Values are mean±SD.

\*Lumbar degenerative spine disease within-group comparisons (p<.017).

# Between-group comparisons (p<.05).

compared with baseline. However, in the between-group comparisons during eyes closed, RMS distance of COP in the DSD group was significantly greater than in the control group at baseline ( $p < .001$ ), as well as at 6 months ( $p = .012$ ) and 12 months ( $p = .006$ ) postoperatively, with mean differences more than  $1.07 \pm 0.84$  mm (Fig. 3D). All significant mean differences in Romberg stance showed moderate effects.

#### *ML direction*

Fig. 4 displays the results of balance control in ML direction during quiet standing. In natural stance, for the DSD within-group comparisons during eyes open, no significant difference was found in RMS distance of COP after lumbar surgery compared with baseline (Fig. 4A). For the DSD within-group comparisons during eyes closed, RMS distance of COP decreased significantly with moderate effect of mean difference  $0.73 \pm 1.28$  mm at 3 months ( $p = .004$ ) and large effect of  $0.56 \pm 0.78$  mm at 6 months ( $p < .001$ ) postoperatively compared with baseline (Fig. 4B). For the between-group comparisons, RMS distance of COP in the DSD group during eyes open and eyes closed were significantly greater than in the control group at baseline, as well as at 6 months and 12 months postoperatively (all  $p < .05$ ), but not at 3 months postoperatively (eyes open,  $p = .072$ ; eyes closed,  $p = .111$ ; Fig. 4A, B). The mean differences of the results between two groups during eyes-open and eyes-closed conditions ranged from  $0.46 \pm 0.16$  mm to  $1.20 \pm 1.67$  mm, showing moderate to large effects.

In Romberg stance, for the DSD within-group comparisons during eyes open, RMS distance of COP decreased significantly with more than  $0.39 \pm 0.05$  mm at 3 months ( $p = .011$ ), 6 months ( $p = .005$ ), and 12 months ( $p = .003$ ) postoperatively compared with the baseline. For the between-group comparisons during eyes open, RMS distance of COP in the DSD group was significantly greater than in the control group at baseline ( $p = .007$ ) only, with a mean difference of  $0.76 \pm 0.33$  mm (Fig. 4C). For the DSD within-group comparisons during eyes closed, RMS distance of COP decreased significantly with a mean difference of  $0.88 \pm 0.49$  mm at 3 months ( $p = .006$ ) and  $0.72 \pm 0.01$  mm at 6 months ( $p = .006$ ) postoperatively compared with baseline. However, for the between-group comparisons during eyes closed, RMS distance of COP in the DSD group was significantly greater than in the control group at baseline ( $p = .013$ ) and at 12 months ( $p = .035$ ) postoperatively (Fig. 4D). The mean differences of the results between two groups during eyes closed were  $1.31 \pm 0.90$  mm at baseline and  $1.06 \pm 0.79$  mm at 12 months postoperatively. All significant mean differences in Romberg stance showed moderate effects.

## **Discussion**

The main purpose of this study was to investigate changes in balance control during quiet standing, pain, and functional activities in individuals with lumbar DSD after

lumbar surgery and to compare them with age-matched healthy adults. The findings supported our hypothesis that balance control of individuals with lumbar DSD during quiet standing, pain, and functional assessments (ODI and RMDQ) improves after lumbar surgery. However, compared with the age-matched healthy adults, the balance control of the individuals with lumbar DSD was less stable both before and after surgery.

#### *Pain level and daily activity function improved after lumbar surgery*

Lumbar surgery showed positive effects on pain and functional activities improvement in individuals with lumbar DSD. The results obtained in our study are in agreement with those obtained in other studies in which researchers have stated that lumbar surgery can immediately alleviate pain and improve the functional activities of individuals with lumbar DSD [13,14]. In our study, significant improvement in pain and functional assessments was not only shown in statistical analysis but also satisfied MCID, which is defined as the smallest change in a treatment outcome that an individual would identify as important.

The subjective functional assessments used for this study were the ODI and the RMDQ. Both subjective assessments improved after lumbar surgery and showed a plateau at 6 months postoperatively. These results were consistent with previous studies in which researchers have stated that lumbar surgery can improve the daily function of individuals with lumbar DSD [34–36]. According to the answers to the clinical questionnaire, the participants were able to perform more daily activities after surgery than before surgery. However, the RMDQ scores at 3 months postoperatively did not show significant improvement compared with preoperatively, but the ODI scores did show improvement. This result could be due to the construct measured by the ODI being broader than that of the RMDQ, such as general health, mental health, and social functioning, whereas RMDQ provides a more focused assessment of physical functioning [37]. Most of the participants in this study reported on the RMDQ that they still needed help for daily activities such as dressing, heavy jobs, and household activities at 3 months postoperatively. Our participants were asked to wear a lumbosacral orthosis in the first 3 months after lumbar surgery [38]. Thus, postoperative fear avoidance could be a factor that caused the participants to avoid trunk movements. An elevated fear-avoidance level was found in participants in the early postoperative period, which is associated with disability and decreased physical health after lumbar surgery [39,40].

Daily activity function and pain level improved after lumbar surgery in this study. However, balance control of individuals with lumbar DSD was still less stable than in the healthy control group, even after lumbar surgery. Analgesic and muscle relaxant were prescribed to the DSD group before and after lumbar surgery, but no medication

### Root Mean Square Distance of COP in Mediolateral Direction

 DSD group       Control group

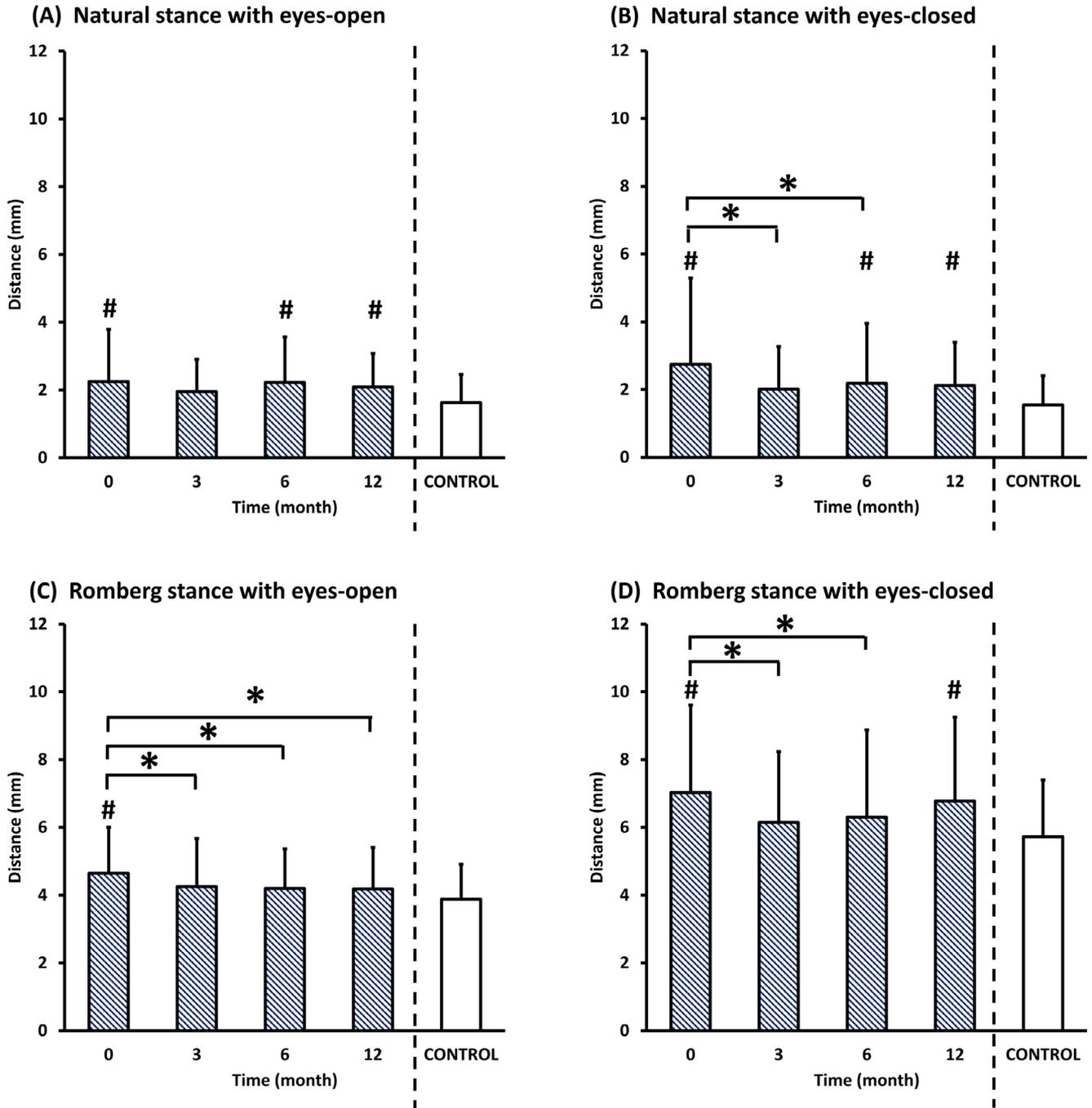


Fig. 4. Root mean square distance of center of pressure in mediolateral direction. Values are mean±SD.

\*Lumbar degenerative spine disease within-group comparisons ( $p < .017$ ).

#Between-group comparisons ( $p < .05$ ).

was prescribed to the healthy control group. Therefore, the side effects of the medication that may cause the differences in balance control between two groups should be considered. Nevertheless, most daily function activities are performed in an upright position, such as walking, running, and jumping. Balance control is a critical demand to execute movement in an upright position. Although the pain level of our individuals with lumbar DSD decreased after lumbar surgery, the balance control of the participants did not fully recover to the level of healthy adults. Thus, other factors such as muscle performance and movement stability should be further examined.

*Balance control of individuals with lumbar DSD showed improvement after surgery but was still less stable than in healthy adults*

Our results showed that balance control in individuals with lumbar DSD improved starting 3 months postoperatively in most of the testing conditions, because their pain and neurological symptoms were relieved by the surgery [41]. In this study, pain levels on the day of testing before surgery were high (mean VAS, 64.7 mm), but they were low at 3 months (mean VAS, 33.5 mm), 6 months (mean VAS, 30.7 mm), and 12 months (mean VAS, 28.5 mm) postoperatively. Thus, when the pain level is decreased, better balance performance in individuals with lumbar DSD would be expected.

Although balance control in the AP direction showed improvement after lumbar surgery, it was still less stable than in healthy adults, particularly in natural stance. Previous studies showed that after lumbar surgery, individuals with lumbar DSD have weaker back muscle strength [9,42] and experience changes in muscle activity, such as a delayed firing time and abnormal recruitment patterns [43]. Trunk muscle strength decreased may result in poor trunk control ability and postural instability [9,44]. In addition, limited lumbar spinal motion and damage of paraspinal muscles may cause abnormal compensatory movements of the body after lumbar surgery. A recent study demonstrated that individuals with lumbar DSD mainly activated their lower limb muscles to compensate their insufficient paraspinal muscle function after receiving lumbar spinal fusion [45]. Therefore, early rehabilitation with back muscle training should be introduced after lumbar surgery.

The balance control in ML direction during quiet standing is governed by the hip abductor and adductor muscles [46,47]. However, muscle weakness and tenderness in hip abductors such as the gluteus medius are common symptoms in individuals with lumbar DSD [48]. Thus, hip abductor weakness may be a factor that affected the balance control of the individuals with lumbar DSD in ML direction before surgery in the present study. Moreover, the balance control of the individuals with lumbar DSD in ML direction at 3 months postoperatively was comparable to that of healthy adults in all standing balance tasks. As mentioned

above, our participants wore a lumbosacral orthosis to protect their spine for the first 3 months postoperatively. A recent study indicated that lumbosacral orthosis decreased postural sway while standing on unstable surfaces [49] and joints coordination are required for balance stability [50,51]. Reduced trunk muscle activation and enhanced proprioception exerted by a lumbosacral orthosis may account for the mechanism underlying the effect of lumbosacral orthosis on balance control. Thus, the decreased postural sway at 3 months postoperatively may result from wearing a lumbosacral orthosis.

However, the balance control of the individuals with lumbar DSD in ML direction became less stable than in healthy adults at 12 months postoperatively, especially during eyes-closed tasks. This finding may be related to poor posture and unhealthy lifestyle remaining unchanged in individuals after lumbar surgery [52], because participants in this study did not receive postoperative rehabilitation. Unhealthy lifestyle habits such as a sedentary lifestyle/insufficient physical activity may lead to lower limb muscle weakness. Recent studies demonstrated that balance control impairment and functional limitations in older adults could be associated with the impaired muscle strength [53] and dynamic stability [54]. Nevertheless, unstable balance control after surgery may increase fall risk of individuals with lumbar DSD during activities of daily living. Therefore, balance assessments and postoperative rehabilitation training for individuals with lumbar DSD after lumbar surgery is necessary.

*Study limitations*

The present study has a few limitations. First, the generalizability of our study findings may be limited because of the lack of follow-up data in the healthy control group. Thus, the effect of aging of the healthy control subjects within 1 year could not be excluded in this study [32]. Second, the present study did not recruit a patient control group since we wanted to know whether the patients could fully recover to the level of healthy adults. Future studies can subgroup participants into surgical and nonsurgical groups for detailed analysis of surgical effects. Third, the lifestyles and physical activities of participants were not monitored in this study. This may cause high variability between participants in postoperative recovery. Thus, future studies should monitor the lifestyles and physical activities of participants during follow-up assessments.

**Conclusions**

Balance control, pain, and functional activities of individuals with lumbar DSD showed improvement after lumbar surgery. However, balance control in individuals with lumbar DSD was still less stable than in age-matched healthy adults from 6 to 12 months after surgery. Therefore, individuals with lumbar DSD may benefit from a fall prevention program after lumbar surgery, such as balance

assessments and postoperative balance training. Future studies should investigate the effect of balance training in individuals with lumbar DSD after lumbar surgery. The findings of this study highlight the importance of balance control assessment and postoperative balance training for individuals with lumbar DSD after lumbar surgery.

## Acknowledgments

This work was supported by the Ministry of Science and Technology (105-2628-E-002-006-MY3; 101-2320-B-002-004-MY3), National Taiwan University (NTU-CDP-107L7733; NTU-CDP-108L7717), and National Health Research Institutes (NHRI-EX105-10218EC).

## Supplementary materials

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.spinee.2019.02.015>.

## References

- [1] Ravindra VM, Senglaub SS, Rattani A, Dewan MC, Härtl R, Bisson E, et al. Degenerative lumbar spine disease: estimating global incidence and worldwide volume. *Glob Spine J* 2018;8:784–94.
- [2] Golob AL, Wipf JE. Low back pain. *Med Clin N Am* 2014;98:405–28.
- [3] Thornes E, Robinson HS, Vollestad NK. Dynamic balance in patients with degenerative lumbar spinal stenosis; a cross-sectional study. *BMC Musculoskelet Disord* 2018;19:192.
- [4] Iversen MD, Kale MK, Sullivan Jr. JT. Pilot case control study of postural sway and balance performance in aging adults with degenerative lumbar spinal stenosis. *J Geriatr Phys Ther* 2009;32:15–21.
- [5] Lin SI, Lin RM. Disability and walking capacity in patients with lumbar spinal stenosis: association with sensorimotor function, balance, and functional performance. *J Orthop Sports Phys Ther.* 2005;35:220–6.
- [6] Allum JH, Bloem BR, Carpenter MG, Hulliger M, Hadders-Algra M. Proprioceptive control of posture: a review of new concepts. *Gait Posture* 1998;8:214–42.
- [7] Leinonen V, Kankaanpää M, Luukkonen M, Kansanen M, Hänninen O, Airaksinen, O, et al. Lumbar paraspinal muscle function, perception of lumbar position, and postural control in disc herniation-related back pain. *Spine* 2003;28:842–8.
- [8] Hughes MA, Duncan PW, Rose DK, Chandler JM, Studenski SA. The relationship of postural sway to sensorimotor function, functional performance, and disability in the elderly. *Arch Phys Med Rehabil* 1996;77:567–72.
- [9] Pao JL, Yang RS, Hsiao CH, Hsu WL. Trunk control ability after minimally invasive lumbar fusion surgery during the early postoperative phase. *J Phys Ther Sci* 2014;26:1165–71.
- [10] Hsu WL, Chen CY, Tsao JY, Yang RS. Balance control in elderly people with osteoporosis. *J Formos Med Assoc* 2014;113:334–9.
- [11] Truszczyńska A, Drzal-Grabiec J, Trzaskoma Z, Rapala K, Tarnowski A, Gorniak K. A comparative analysis of static balance between patients with lumbar spinal canal stenosis and asymptomatic participants. *J Manip Physiol Ther* 2014;37:696–701.
- [12] Yen TC, Toosizadeh N, Howe C, Dohm M, Mohler J, Najafi B. Postural balance parameters as objective surgical assessments in low back disorders: a systematic review. *J Appl Biomech* 2016;32:316–23.
- [13] Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. *Spine* 2009;34:1094–109.
- [14] Bydon M, De la Garza-Ramos R, Macki M, Baker A, Gokaslan AK, Bydon A. Lumbar fusion versus nonoperative management for treatment of discogenic low back pain: a systematic review and meta-analysis of randomized controlled trials. *J Spinal Disord Tech* 2014;27:297–304.
- [15] Qaseem A, Wilt TJ, McLean RM, Forciea MA, Clinical Guidelines Committee of the American College of Physicians. Noninvasive treatments for acute, subacute, and chronic low back pain: a clinical practice guideline from the American College of Physicians. *Ann Intern Med* 2017;166:514–30.
- [16] Dagenais S, Tricco AC, Haldeman S. Synthesis of recommendations for the assessment and management of low back pain from recent clinical practice guidelines. *Spine J* 2010;10:514–29.
- [17] Koenders N, Rushton A, Verra ML, Willems PC, Hoogbeem TJ, Staal JB. Pain and disability after first-time spinal fusion for lumbar degenerative disorders: a systematic review and meta-analysis. *Eur Spine J* 2018. [Epub ahead of print].
- [18] Levin JM, Tanenbaum JE, Steinmetz MP, Mroz TE, Overley SC. Posterolateral fusion (PLF) versus transforaminal lumbar interbody fusion (TLIF) for spondylolisthesis: a systematic review and meta-analysis. *Spine J* 2018;18:1088–98.
- [19] Cho JH, Joo YS, Lim C, Hwang CJ, Lee DH, Lee CS. Effect of one- or two-level posterior lumbar interbody fusion on global sagittal balance. *Spine J* 2017;17:1794–802.
- [20] Forsth P, Olafsson G, Carlsson T, Frost A, Borgström F, Fritzell P, et al. A Randomized, controlled trial of fusion surgery for lumbar spinal stenosis. *N Engl J Med* 2016;374:1413–23.
- [21] Smuck M, Muaremi A, Zheng P, Norden J, Sinha A, Hu R, et al. Objective measurement of function following lumbar spinal stenosis decompression reveals improved functional capacity with stagnant real-life physical activity. *Spine J* 2018;18:15–21.
- [22] Sipko T, Chantsoulis M, Kuczynski M. Postural control in patients with lumbar disc herniation in the early postoperative period. *Eur Spine J* 2010;19:409–14.
- [23] Bouche K, Stevens V, Cambier D, Caemaert J, Danneels L. Comparison of postural control in unilateral stance between healthy controls and lumbar discectomy patients with and without pain. *Eur Spine J* 2006;15:423–32.
- [24] Truszczyńska A, Drzal-Grabiec J, Trzaskoma Z, Rachwał M, Rapala K, Gorniak K. Static balance after surgical decompression of lumbar spinal canal stenosis. *J Back Musculoskelet Rehabil* 2015;28:865–71.
- [25] Hsu WL. Adaptive postural control for joint immobilization during multitask performance. *PLoS One* 2014;9:e108667.
- [26] Bijur PE, Silver W, Gallagher EJ. Reliability of the visual analog scale for measurement of acute pain. *Acad Emerg Med* 2001;8:1153–7.
- [27] Vlaeyen JW, Kole-Snijders AM, Boeren RG, van Eek H. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain* 1995;62:363–72.
- [28] Mannion AF, Junge A, Fairbank JC, Dvorak J, Grob D. Development of a German version of the Oswestry disability index. Part 1: cross-cultural adaptation, reliability, and validity. *Eur Spine J* 2006;15:55–65.
- [29] Miekisiak G, Kollataj M, Dobrogowski J, et al. Validation and cross-cultural adaptation of the Polish version of the Oswestry Disability Index. *Spine* 2013;38:E237–43.
- [30] Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY. Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry Disability Index, Medical Outcomes Study questionnaire Short Form 36, and pain scales. *Spine J* 2008;8:968–74.
- [31] Ostelo RW, de Vet HC, Knol DL, van den Brandt PA. 24-item Roland-Morris Disability Questionnaire was preferred out of six functional status questionnaires for post-lumbar disc surgery. *J Clin Epidemiol* 2004;57:268–76.

- [32] Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng* 1996;43:956–66.
- [33] Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. *J Sport Rehabil* 2002;11:51–66.
- [34] Rodriguez-Vela J, Lobo-Escobar A, Joven-Aliaga E, Herrera A, Vicente J, Suñén E, et al. Perioperative and short-term advantages of mini-open approach for lumbar spinal fusion. *Eur Spine J* 2009;18:1194–201.
- [35] Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. *Eur Spine J* 2009;18:672–8.
- [36] Anand N, Baron EM, Bray RS. Benefits of the paraspinal muscle-sparing approach versus the conventional midline approach for posterior nonfusion stabilization: comparative analysis of clinical and functional outcomes. *SAS J* 2007;1:93–9.
- [37] Chiarotto A, Maxwell LJ, Terwee CB, Wells GA, Tugwell P, Ostelo RW. Roland-Morris Disability Questionnaire and Oswestry Disability Index: which has better measurement properties for measuring physical functioning in nonspecific low back pain? Systematic review and meta-analysis. *Phys Ther* 2016;96:1620–37.
- [38] Zhu MP, Tetreault LA, Sorefan-Mangou F, Garwood P, Wilson JR. Efficacy, safety, and economics of bracing after spine surgery: a systematic review of the literature. *Spine J* 2018;18:1513–25.
- [39] Archer KR, Seebach CL, Mathis SL, Riley 3rd LH, Wegener ST. Early postoperative fear of movement predicts pain, disability, and physical health six months after spinal surgery for degenerative conditions. *Spine J* 2014;14:759–67.
- [40] Donnarumma P, Presaghi F, Tarantino R, Fragale M, Rullo M, Delfini R. The impact of pelvic balance, physical activity, and fear-avoidance on the outcome after decompression and instrumented fusion for degenerative lumbar stenosis. *Eur Spine J* 2017;26:428–33.
- [41] Sipko T, Kuczynski M. The effect of chronic pain intensity on the stability limits in patients with low back pain. *J Manipulative Physiol Ther* 2013;36:612–8.
- [42] Kramer M, Katzmaier P, Eisele R, Ebert V, Kinzl L, Hartwig E. Surface electromyography-verified muscular damage associated with the open dorsal approach to the lumbar spine. *Eur Spine J* 2001;10:414–20.
- [43] Cha JR, Kim YC, Jang C, Yoo WK, Cui JH. Pedicle screw fixation and posterior fusion for lumbar degenerative diseases: effects on individual paraspinal muscles and lower back pain; a single-center, prospective study. *BMC Musculoskelet Disord* 2016;17:63.
- [44] Parreira RB, Amorim CF, Gil AW, Teixeira DC, Bilodeau M, da Silva RA. Effect of trunk extensor fatigue on the postural balance of elderly and young adults during unipodal task. *Eur J Appl Physiol* 2013;113:1989–96.
- [45] Wang TY, Pao JL, Yang RS, Jang JS, Hsu WL. The adaptive changes in muscle coordination following lumbar spinal fusion. *Hum Mov Sci* 2015;40:284–97.
- [46] Winter DA, Prince F, Frank JS, Powell C, Zabjek KF. Unified theory regarding A/P and M/L balance in quiet stance. *J Neurophysiol* 1996;75:2334–43.
- [47] Winter DA. Human balance and posture control during standing and walking. *Gait Posture* 1995;3:193–214.
- [48] Cooper NA, Scavo KM, Strickland KJ, Tipayamongkol N, Nicholson JD, Bewyer DC, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. *Eur Spine J* 2016;25:1258–65.
- [49] Mi J, Ye J, Zhao X, Zhao J. Effects of lumbosacral orthoses on postural control in individuals with or without non-specific low back pain. *Eur Spine J* 2018;27:180–6.
- [50] Hsu WL, Lin KH, Yang RS, Cheng CH. Use of motor abundance in old adults in the regulation of a narrow-based stance. *Eur J Appl Physiol* 2014;114:261–71.
- [51] Hsu WL, Scholz JP. Motor abundance supports multitasking while standing. *Hum Mov Sci* 2012;31:844–62.
- [52] Chou YC, Shih CC, Lin JG, Chen TL, Liao CC. Low back pain associated with sociodemographic factors, lifestyle and osteoporosis: a population-based study. *J Rehabil Med* 2013;45:76–80.
- [53] Porto JM, Freire Junior RC, Bocarde L, Fernandes JA, Marques NR, Rodrigues NC, et al. Contribution of hip abductor-adductor muscles on static and dynamic balance of community-dwelling older adults. *Aging Clin Exp Res* 2018. [Epub ahead of print].
- [54] Chien JE, Hsu WL. Effects of dynamic perturbation-based training on balance control of community-dwelling older adults. *Sci Rep* 2018;8:17231.