J Rehabil Med 2018; 50: 898–907

ORIGINAL REPORT

Check for updates

SPINO-PELVIC ALIGNMENT, BALANCE, AND FUNCTIONAL DISABILITY IN PATIENTS WITH LOW-GRADE DEGENERATIVE LUMBAR SPONDYLOLISTHESIS

Chien-Yi CHUANG, MD[1#], Mei-Yun LIAW, MD[1#], Lin-Yi WANG, MD[1], Yu-Chi HUANG, MD[1], Ya-Ping PONG, MD[1], Chien-Wei CHEN, PT[2], Re-Wen WU, MD[3] and Yiu-Chung LAU, MD[1]

From the [1]Department of Physical Medicine and Rehabilitation and [3]Department of Orthopedic Surgery, Kaohsiung Chang Gung Memorial Hospital, Chang Gung University College of Medicine and [2]Department of Physical Therapy, Kaohsiung Chang Gung Memorial Hospital, Kaohsiung, Taiwan

[#]These authors should be considered as first authors.

Objective: **To evaluate the relationships among spino-pelvic parameters, trunk balance and functional disability in patients with degenerative lumbar spondylolisthesis.**

Design: **Cross-sectional study.**

Subjects: **Forty-five patients with degenerative lumbar spondylolisthesis and 32 patients without degenerative lumbar spondylolisthesis.**

Methods: **Spino-pelvic parameters (pelvic incidence, pelvic tilt, sacral slope, lumbar lordosis) and pain severity were evaluated. Biodex balance tests (postural stability, limits of stability, modified clinical test of sensory interaction and balance, fall risk) and Quebec Back Pain Disability Scale (QBDS) scores were measured.**

Results: **Intergroup differences were found in age, low back pain, limits of stability, pelvic incidence, pelvic tilt and some subscales of QBDS. Correlations were found: (*i*) in the degenerative lumbar spondylolisthesis group: between pelvic incidence and sacral slope/pelvic tilt/lumbar lordosis/height/limits of stability; sacral slope and lumbar lordosis/height/limits of stability/modified clinical test of sensory interaction and balance (eyes closed on foam); lumbar lordosis and body mass index/QBDS/postural stability/modified clinical test of sensory interaction and balance (eyes open and eyes closed on foam); (*ii*) in the non-degenerative lumbar spondylolisthesis group: between pelvic incidence and pelvic tilt; pelvic tilt and sacral slope/lumbar lordosis; sacral slope and lumbar lordosis/fall risk. All spino-pelvic parameters in the degenerative lumbar spondylolisthesis group and pelvic tilt in the non-degenerative lumbar spondylolisthesis group correlated with QBDS.**

Conclusion: **Pelvic tilt was the major compensating factor in both groups (patients with and without degenerative lumbar spondylolisthesis). Sacral slope and lumbar lordosis contributed to partial compensation in the degenerative lumbar spondylolisthesis group. Lumbar lordosis correlated with body mass index. Sacral slope could be an indicator of fall risk in the non-degenerative lumbar spondylolisthesis group.**

Key words: spino-pelvic alignment; balance; functional disability; degenerative lumbar spondylolisthesis; degenerative spondylosis.

Accepted Aug 7, 2018; Epub ahead of print Oct 11, 2018

LAY ABSTRACT

Low-grade degenerative lumbar spondylolisthesis (DLS) is defined as less than 50% slippage of a lumbar vertebral body over the next most caudal vertebral body. Patients with DLS usually experience back pain, leg pain, and even falls.The pain intensity, static and dynamic balance, functional disability, and the spino-pelvic parameters of the radiography (pelvic incident, pelvis tilt, sacral slope, lumbar lordosis) were compared between the patients with DLS and without DLS (non-DLS).The results revealed that DLS patients were older, had greater angle of pelvic incidence and pelvic tilt, less stability and more low back pain than non-DLS patients.The pelvic tilt was the major compensating factor of spino-pelvic balance in both groups. Lumbar lordosis is positively related to body mass index. Sacral slope and lumbar lordosis contributed to partial compensation of balance of spino-pelvic alignment in DLS patients, whereas sacral slope could be an indicator of fall risk in non-DLS patients.

J Rehabil Med 2018; 50: 898–907

Correspondence address: Mei-Yun Liaw, Department of Physical Medicine and Rehabilitation, Kaohsiung Chang Gung Memorial Hospital, Chang Gung University College of Medicine, 123, Da Pi Road, Niao Song District, Kaohsiung 83301, Taiwan, ROC. E-mail: meiyunliaw@cgmh.org.tw

Degenerative lumbar spondylolisthesis (DLS) is defined as slippage of a vertebral body in the lumbar region by at least 5% in relation to the next most caudal vertebral body with an intact neural arch (1). Low-grade DLS is defined as translation of a vertebra by less than 50% (2). Patients with DLS usually experience recurrent or constant low back pain (LBP) with muscle weakness or spasm, radicular pain, unsteady gait, intermittent claudication and even unexpected falls (3). DLS is common in individuals older than 50 years. The prevalence of DLS in a study of elderly Chinese people was 3% in men and 6% in women (1). DLS is related to the progressive degeneration of bilateral subluxed facet joints and intervertebral discs.

Normally, the pelvis rotates around the bicoxofemoral axis (4). The imbalance in spino-pelvic alignment usually results in tension over the facet joints, capsule and ligaments, and overuse of stabilizing muscles of the lumbar spine.

This is an open access article under the CC BY-NC license. www.medicaljournals.se/jrm

doi: 10.2340/16501977-2489

Journal Compilation © 2018 Foundation of Rehabilitation Information. ISSN 1650-1977

Spino-pelvic parameters, such as pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT) and lumbar lordosis (LL), have been suggested to be predisposing factors for DLS (2, 5–10). PI is an anatomical parameter. It is the main axis of the sagittal balance of the spine (11). PI is constant, whereas PT and SS are both positional variables. The PT and SS angles are directly correlated with the PI angle. The PT angle increases with pelvic backward rotation (retroversion) and decreases with pelvic forward rotation (anteversion) (4). Morel et al. (12) reported that high PI, hyperlordosis and increased PT favoured progressive degeneration of the spine in patients with degenerative spondylolisthesis. Hresko et al. (2) stated that a high mean PI (78.9° (standard deviation (SD) 12.1°)) was noted in patients with high-grade spondylolisthesis. An association between abnormal sagittal alignment and LBP was also established (13, 14).

Postural balance also depends on the availability and central processing of visual, vestibular and proprioceptive inputs.

The Biodex Balance System (BBS) is used for static and dynamic balance tests. It requires coordination of the lower limbs and core muscles against the perturbing effect of gravity on the unstable platform during a dynamic test. BBS can objectively measure trunk instability, screen fall risk, and provide a conditioning programme to improve or maintain static or dynamic postural stability (15, 16). Good reliability in dynamic postural balance in normal patients (intra-class correlation coefficients 0.91–0.95) has been reported (17).

The Quebec Back Pain Disability Scale (QBDS) has been found to have high reliability (r = 0.92), and has been recommended for monitoring the degree of functional disability (18).

Studies regarding the correlations between spino-pelvic alignment and balance or functional performance in patients with low-grade DLS are rare.

The aims of this study were to investigate the relationships among spino-pelvic parameters and clinical characteristics, static and dynamic trunk balance and LBP functional disability in patients with or without low-grade spondylolisthesis, in order to provide strategies for postural adjustment and a more specific rehabilitation programme.

METHODS

Settings

This prospective, cross-sectional study recruited patients from October 2014 to July 2017 from the outpatient clinic of the Department of Physical Medicine and Rehabilitation at Kaohsiung Chang Gung Memorial Hospital, Kaohsiung in southern Taiwan. Participants were provided with detailed information about the study, and all gave their informed consent. The study was approved by the Institutional Review Board of Kaohsiung Chang Gung Memorial Hospital (102-6100A3) and registered as a clinical trial (NCT02435485).

Participants

A total of 77 participants, age range 50–80 years, who had LBP and lumbosacral radiographs were enrolled. The patients were divided into 2 groups according to their radiographic diagnosis: 45 patients (36 females, 9 males) in the DLS group and 32 patients (21 females, 11 males) in the non-DLS group.

Patients with stroke, spinal cord injury, head injury or other neurological deficits, neoplasm, infectious or inflammatory disease, visual or hearing impairments without adequate correction, vertebral fracture, isthmic lumbar spondylolisthesis, leg-length discrepancy, or cognitive impairment, and those taking sedatives were excluded.

Clinical measurements

Age, sex, body weight, body height, body mass index (BMI), and scores for numeric pain scale (NPS) for low back and radicular pain and the QBDS were recorded (Table I).

Radiological measurements

Each patient underwent radiography of the kidneys, ureter, and bladder (KUB) and the lateral lumbosacral spine in the neutral posture to examine radiological parameters, including PI, PT, SS and LL, the level involved, and the degree of slippage using the classification of Meyerding (19). The lateral view was taken in a standardized lateral recumbent position with knees flexed (20).

Table I. Clinical characteristics and radiographic parameters in degenerative lumbar spondylolisthesis (DLS) and non-DLS groups

Characteristics/group	DLS ($n = 45$) Grade I ($n = 40$, 88.8%) Grade II ($n = 5$, 11.1%)	Non-DLS ($n = 32$)	*p*-value
Sex, *n* (%)			
Male	9 (20)	11 (34.4)	
Female	36 (80)	21 (65.6)	
Age, years, mean (SD)	63.7 (5.8)	60.5 (7.1)	0.036*
Height, cm, mean (SD)	158.1(6.6)	159.9 (6.0)	0.228
Weight, kg, mean (SD)	60.8 (8.2)	62.8 (10.3)	0.351
Body mass index, kg/m^2, mean (SD)	24.3 (3.1)	24.5 (3.3)	0.825
Radiographic parameters, mean (SD)			
Pelvic incidence	52.8 (11.1)	45.6 (8.0)	0.008**
Sacral slope	32.9 (8.4)	31.0 (9.42)	0.408
Pelvic tilt	20.1 (9.8)	14.3 (9.8)	0.026*
Lumbar lordosis	44.9 (11.7)	43.9 (12.5)	0.739
Numeric pain scale			
Low back pain, mean (SD)	4.5 (2.1)	3.4 (1.7)	0.026*
median (IQR)	4.0 (2.5)	3.5 (3.0)	
Radicular pain, mean (SD)	2.4 (2.7)	1.9 (2.0)	0.700
median (IQR)	2.0 (5.0)	2.0 (3.0)	
Quebec Back Pain Disability Scale			
mean (SD)	15.4 (9.5)	15.0 (8.0)	0.988
median (IQR)	15.0 (12.0)	14.0 (13.5)	

**p*-value use independent *t*-test or Mann–Whitney *U* test. *$p < 0.05$; **$p < 0.01$. Interquartile range: (IQR) = Q3–Q1, median = Q2.

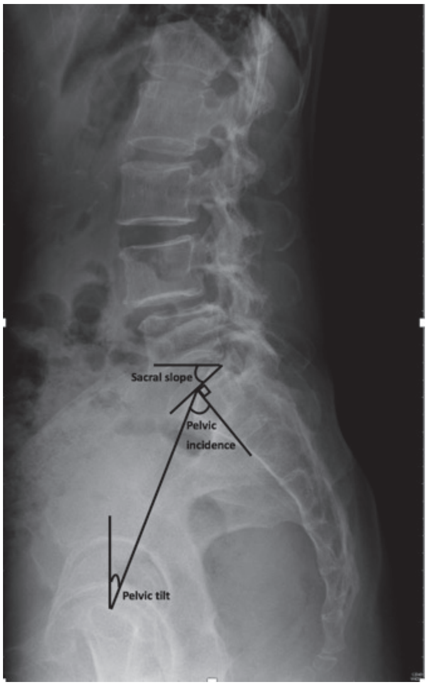

Fig. 1. Spinopelvic parameters: pelvic tilt, pelvic incidence, and sacral slope.

Spino-pelvic parameters (Figs 1 and 2)

1. PI: defined as the angle subtended by a line perpendicular to and passing through the midpoint at the end-plate of the sacrum, and the line from the midpoint of the sacral plate to the axis of the femoral heads (2, 11).
2. SS: the angle between the upper sacral endplate and a horizontal line (11).

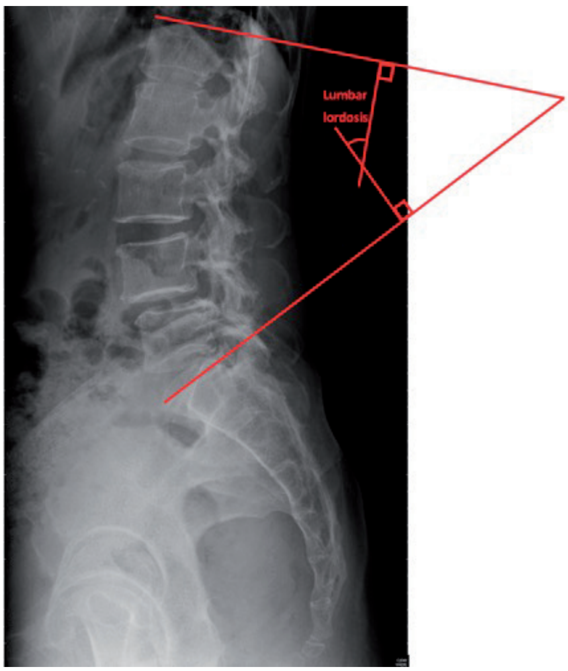

Fig. 2. Spinopelvic parameter: lumbar lordosis.

3. PT: the angle between the line from the centre of the femoral head to the midpoint of the upper plate of S1 and the vertical line (11).
4. LL: the angle between the upper endplate of L1 and the upper endplate of S1 (21).

Quebec Back Pain Disability Scale

The QBDS was used to gain information about the activities of daily living affected by LBP (18). It consists of 20 activities with a scale of 0–5 points (22).

Balance measurement (23)

BBS (Biodex Medical System Inc., Shirly, New York, USA) was used to assess balance and postural stability. Participants were instructed to place their bare feet on the platform, assuming a comfortable position to maintain a quiet stance for 10 seconds for initialization, while looking straight ahead. The midline of the foot and the platform grid were used as reference points. The test stopped when a participant grasped a handle, took a step, lifted their heel off the platform, stumbled, fell, or opened their eyes during the eyes closed test.

1. *Postural Stability (PS) test:* this test emphasizes a patient's ability to maintain a centre of balance. It consists of 3 trials while standing on a static platform for 20 s per trial with eyes open. The 3 measurements, namely the overall stability index (OSI), anterior-posterior stability index, and medial-lateral stability index, were recorded. The mean score was calculated from the 3 trials. The stability index is the score that assesses deviations from centre. A higher score indicates excessive motion during the test, and is less desirable.
2. *Limits of Stability (LOS) test (75% LOS)*: the default setting for the LOS test is 75% LOS (moderate still level). The test is an indicator of dynamic control. Nine blinking targets were shown randomly on the screen. Patients were instructed to move and control their centre of gravity within their base of support. During each test trial, the patients have to shift their weight with the least deviation possible to move the cursor on the screen from the central target to the blinking target and back as quickly as they can. This test challenges patients to move and control their center of gravity within their base of support. The same process was repeated for each of the 9 targets. There was a 10-s rest period every 3 trials. The direction control of overall, forward, backward, right, left, forward/right (F/R), forward/left (F/L), backward/right (B/R) and backward/left (B/L) movement, and the time needed to complete the test were recorded. A higher score was more desirable. The test score is counted by the BBS machine (23).
3. *Modified Clinical Test of Sensory Interaction and Balance (m-CTSIB):* this test comprises 4 conditions, each lasting 30 s: Condition 1: eyes open (EO) on a firm surface; Condition 2: eyes closed (EC) on a firm surface; Condition 3: EO on a dynamic surface; Condition 4: EC on a dynamic surface. The sway index (the standard deviation of the stability index) was recorded. This could objectively quantify the m-CTSIB with a time-based pass/fail for completing the test in 30 s without falling, or assign a value of 1–4 to characterize the sway. Score 1 indicates minimal sway, whereas score 4 indicates a fall. The higher the sway index, the more unsteady the person was during the test.
4. *Fall risk test:* this test is used to identify potential fall candidates. Patients were asked to maintain their balance during each trial. Three trials lasting 20 s per trial were performed.

Journal of Rehabilitation Medicine JRM

JRM Journal of Rehabilitation Medicine JRM Journal of Rehabilitation Medicine JRM

Table II. Baseline balance evaluations in degenerative lumbar spondylolisthesis (DLS) and non-DLS groups

	DLS ($n=45$)		Non-DLS ($n=32$)		
Group	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	*p*-value
Postural stability test					
Overall	1.5 (1.4)	0.9 (1.3)	1.5 (1.1)	1.2 (1.6)	**0.663**
Anterior/Posterior	1.1 (1.2)	0.7 (0.9)	1.1 (0.9)	0.9 (0.9)	**0.504**
Medial/Lateral	0.7 (0.9)	0.4 (0.7)	0.8 (0.7)	0.5 (1.1)	**0.550**
Limits of stability test					
Time to complete (s)	151.6 (114.9)	149.0 (179.0)	110.1 (92.4)	63.0 (130.0)	**0.114**
Overall	35.3 (11.7)	35.0 (15.0)	38.2 (10.1)	38.0 (8.8)	**0.179**
Forward	44.5 (20.6)	44.0 (33.0)	50.9 (16.2)	53.5 (23.5)	**0.142**
Back	38.5 (17.5)	36.0 (27.5)	45.6 (16.5)	46.5 (27.3)	**0.060**
Right	43.6 (14.3)	45.0 (20.5)	45.2 (13.8)	45.0 (17.5)	**0.729**
Left	45.7 (12.5)	44.0 (17.0)	52.3 (14.7)	50.0 (23.3)	**0.049***
Forward/Right	43.0 (13.6)	43.0 (17.5)	47.9 (14.9)	47.0 (19.3)	**0.186**
Forward/Left	42.3 (14.0)	43.0 (18.0)	46.9 (11.7)	50.0 (20.3)	**0.074**
Back/Right	36.6 (14.1)	35.0 (23.5)	37.4 (15.1)	38.0 (26.0)	**0.690**
Back/Left	34.8 (14.9)	30.0 (18.5)	36.8 (17.3)	35.5 (24.5)	**0.725**
Modified clinical test of sensory integration					
Eyes open firm	0.8 (0.4)	0.7 (0.3)	0.9 (0.6)	0.7 (0.3)	**0.605**
Eyes closed firm	1.1 (0.5)	1.0 (0.7)	1.1 (0.5)	1.1 (0.9)	**0.800**
Eyes open foam	1.4 (0.8)	1.2 (0.6)	1.4 (0.5)	1.2 (0.7)	**0.760**
Eyes closed foam	3.3 (1.2)	3.0 (1.0)	3.3 (1.0)	3.1 (1.4)	**0.901**
Fall risk test	1.2 (0.8)	1.0 (1.0)	1.2 (0.7)	1.1 (0.8)	**0.784**

*$p<0.05$; **$p<0.01$. **p*-value use independent *t*-test or Mann–Whitney *U* test; IQR: interquartile range = Q3–Q1, median = Q2.
SD: Standard deviation.

The initial platform setting was level 12, which was the most stable. The final platform setting was level 8, which was the least stable. The dynamic balance platform was systemically changed, and patients were asked to maintain their balance in the innermost zone during each trial. Fall risk score was recorded and compared with age-dependent normative data. Scores higher than normative values were less desirable.

Statistical methods

SPSS software (SPSS v22.0, Chicago, IL, USA) was used to analyse the data. Data were expressed as means (SD) or medians (IQR). Independent Student's *t*-test or Mann–Whitney *U* test were used to compare parameters between DLS and non-DLS groups. Pearson or Spearman correlation tests were used to analyse correlations between spino-pelvic parameters and clinical characteristics, BBS test scores, and QBDS in each group. The threshold for statistical significance was set at $p<0.05$. Factors with *p*-value <0.1 from Tables I, II and III were chosen, and multiple binary logistic regression by stepwise method was applied to estimate the odds ratio.

No prospective sample size calculations were made. However, a retrospective calculation based on data for PI in Table I was selected to calculate sample size. The results show that group sample sizes of 45 and 32 achieve 90.4% power to reject the null hypothesis of equal means when the population mean difference was 7.2, with SD of 11.1 for group 1, and 8.0 for group 2, and with a significance level of 0.050, using a 2-sided 2-sample unequal-variance *t*-test (PASS 14.0).

Table III. Numbers and level of spondylolisthesis in degenerative lumbar spondylolisthesis (DLS) group ($n=45$)

Spondylolisthesis level	*n* (%)
L3L4	3 (6.67)
L4L5	26 (57.78)
L5S1	4 (8.89)
L3L4L5	4 (8.89)
L4L5S1	5 (11.12)
L2345	1 (2.23)
L345S1	2 (4.45)

RESULTS

No participants fell during any of the tests. The clinical characteristics, radiographic parameters and baseline balance evaluations in DLS and non-DLS groups are shown in Tables I and II. The numbers and level of spondylolisthesis in the DLS group is shown in Table III. There was a significant difference between the 2 groups in terms of age ($p = 0.036$), PI ($p = 0.008$), PT ($p = 0.026$), LBP ($p = 0.026$), and limit of stability in the leftwards direction ($p = 0.049$), climbing a flight of stairs, running approximately 100 m, and bending over to clean the bathtub (Tables I, II, IV).

In the DLS group, statistically significant correlations were found between the following variables: (*i*) spino-pelvic parameters (Table V): PI and SS ($r=0.540$, $p<0.01$); PI and PT ($r=0.679$, $p<0.01$); PI and LL ($r=0.348$, $p<0.05$); SS and LL ($r=0.693$, $p<0.01$); (*ii*) spino-pelvic parameters and clinical characteristics (Table VI): PI and height ($r = -0.449$, $p<0.01$); SS and height ($r=-0.360$, $p<0.05$); LL and BMI ($r=0.309$, $p<0.05$); LL and QBDS ($r=-0.377$, $p<0.05$); (*iii*) spino-pelvic parameters and balance evaluations (Table VII): PI and LOS(F/R) ($r=0.352$, $p<0.05$); SS and LOS (F/R) ($r=0.346$, $p<0.05$); SS and EC (foam) ($r=0.383$, $p<0.05$); LL and PS-overall ($r=0.378$, $p<0.05$), LL and PS-anterior-posterior (AP) ($r=0.389$, $p<0.01$), LL and EO(foam) ($r=0.307$, $p<0.05$), LL and EC (foam) ($r=0.361$,

Table IV. Quebec subscale scores in the degenerative lumbar spondylolisthesis (DLS) group ($n=45$) and non-DLS group ($n=32$)

Quebec subscale scores	Spondylolisthesis group ($n=45$) Mean (SD)	Spondylosis group ($n=32$) Mean (SD)	p-value
Quebec1	0.67 (1.11)	0.66 (0.94)	0.603
Quebec2	1.04 (1.38)	1.03 (1.15)	0.664
Quebec3	0.47 (0.76)	0.69 (1.03)	0.380
Quebec4	1.51 (2.26)	1.03 (1.64)	0.823
Quebec5	0.78 (0.10)	0.78 (0.83)	0.695
Quebec6	0.56 (0.81)	0.91 (1.03)	0.132
Quebec7	0.51 (0.94)	0.84 (0.88)	0.025
Quebec8	0.44 (0.97)	0.56 (0.80)	0.206
Quebec9	1.27 (1.48)	1.44 (1.37)	0.422
Quebec10	0.42 (1.10)	0.31 (0.69)	0.949
Quebec11	0.36 (1.09)	0.06 (0.25)	0.194
Quebec12	2.69 (2.29)	1.31 (1.87)	0.005
Quebec13	0.20 (0.66)	0.25 (0.51)	0.336
Quebec14	0.38 (0.83)	0.41 (0.67)	0.529
Quebec15	0.42 (0.94)	0.41 (0.62)	0.445
Quebec16	0.71 (0.92)	1.25 (1.08)	0.013
Quebec17	0.24 (0.57)	0.44 (0.62)	0.088
Quebec18	0.56 (0.69)	0.63 (0.87)	0.885
Quebec19	0.38 (0.65)	0.69 (0.78)	0.056
Quebec20	2.00 (1.62)	1.63 (1.39)	0.364

*Mann–Whitney test.
*Quebec1: Get out of bed; 2: Sleep through the night; 3: Turn over in bed; 4: Ride in a car; 5: Stand up for 20–30 min; 6: Sit in a chair for several hours; 7: Climb a flight of stairs; 8: Walk a few blocks (300–400 m); 9: Walk several km; 10: Reach up to high shelves; 11: Throw a ball; 12: Run 1 block (approximately 100 m); 13: Take food out of the refrigerator; 14: Make your bed; 15: Put on socks (pantyhose); 16: Bend over to clean the bathtub; 17: Move a chair; 18: Pull or push heavy doors; 19: Carry 2 bags of groceries; 20: Lift and carry a heavy suitcase.

$p<0.05$); (*iv*) spino-pelvic parameters and Quebec subscale scores (Table VIII): PI and walking several km (r=–0.359, $p<0.05$); PT and walking several km (r=–0.359, $p<0.05$); PT and running approximately 100 m (r=–0.321, $p<0.05$); SS and climbing a flight of stairs (r=–0.415, $p<0.01$); SS and making the bed (r=–0.481, $p<0.01$); SS and pulling or pushing heavy doors (r=–0.307, $p<0.05$); SS and lifting and carrying a heavy suitcase (r=–0.349, $p<0.05$); LL and climbing a flight of stairs (r=–0.345, $p<0.05$); LL and making the bed (r=–0.462, $p<0.01$); LL and bending over to clean the bathtub (r=–0.329, $p<0.05$); LL and lifting and carrying a heavy suitcase (r=–0.350, $p<0.05$).

In the non-DLS group, statistically significant correlations were found between the following variables: (*i*) spino-pelvic parameters (Table V): PI and PT (r=0.463, $p<0.05$); PT and SS (r=–0.650, $p<0.01$); PT and LL (r=–0.559, $p<0.01$); SS and LL (r=0.644, $p<0.01$); (*ii*) spino-pelvic parameters and balance evaluations (Table VII): SS and fall risk (r=0.415, $p<0.05$); (*iii*) spino-pelvic parameters and Quebec subscale scores (Table VIII): PT and bending over to clean the bathtub (r=–0.522, $p<0.05$).

Multiple binary logistic regression was used to demonstrate that the odds ratio for DLS and LBP was 1.49 (1.07–2.07, $p<0.05$), and for DLS and PI was 1.08 (1.02–1.15, $p<0.01$) (Table IX).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the correlations among spino-pelvic alignment, anthropometric variables, balance performance and functional limitation in patients with low-grade DLS. Most of the participants were female (80% in DLS and 65.6% in non-DLS groups), similar previous studies (8). In our study, the DLS group, on average, was older, had greater PI and PT, had lower scores of LOS test, and experienced more LBP than the non-DLS

Table V. Correlation between the spino-pelvic parameters of the degenerative lumbar spondylolisthesis (DLS) group ($n=45$) and non-DLS group ($n=32$)

	DLS			Non-DLS		
Parameters (degree)	Pelvic incidence	Pelvic tilt	Sacral slope	Pelvic incidence	Pelvic tilt	Sacral slope
Pelvic incidence	1	0.679**	0.540**	1	0.463*	0.363
Sacral slope	0.540**	−0.244	1	0.363	−0.650**	1
Pelvic tilt	0.679**	1	−0.244	0.463*	1	−0.650*
Lumbar lordosis	0.348*	−0.198	0.693**	0.065	−0.559**	0.644**

*Pearson correlation test. *$p<0.05$; **$p<0.01$.

Table VI. Correlation between the spino-pelvic parameters and clinical characteristics of the degenerative lumbar spondylolisthesis (DLS) group ($n=45$) and non-DLS group ($n=32$)

	DLS ($n=45$)				Non-DLS ($n=32$)			
Parameters	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis
Age, years	0.257	0.166	0.148	0.190	−0.191	−0.005	−0.202	−0.260
Height, cm	−0.449**	−0.174	−0.360*	−0.199	0.179	0.081	0.051	0.367
Weight, kg	−0.186	−0.171	−0.034	0.173	0.235	0.301	−0.150	−0.024
BMI, kg/m^2	0.077	−0.081	0.189	0.309*	0.159	0.326	−0.236	−0.236
NPS								
Low back	−0.113	−0.094	−0.030	−0.083	−0.018	−0.144	0.031	0.036
Radicular	0.355*	0.270	0.180	−0.108	0.255	0.221	−0.041	−0.163
QBDS	−0.099	0.123	−0.276	−0.377*	0.108	0.095	0.053	0.309

Pearson correlation test and Spearman test. ($p<0.05$; **$p<0.01$).
NPS: numeric pain scale; BMI: body mass index; QBDS: Quebec Back Pain Disability Scale.

JRM Journal of Rehabilitation Medicine JRM Journal of Rehabilitation Medicine JRM

Table VII. Correlation between the spino-pelvic parameters and Biodex balance test scores of the degenerative lumbar spondylolisthesis (DLS) group and non-DLS group

	DLS ($n=45$)				Non-DLS ($n=32$)			
Parameters	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis
Postural stability test								
Overall	0.220	0.001	0.268	0.378*	0.038	−0.098	0.144	0.175
Anterior/Posterior	0.168	−0.075	0.251	0.389**	−0.033	−0.200	0.211	0.273
Medial/Lateral	0.135	0.062	0.142	0.210	0.109	−0.072	0.175	0.240
Limits of stability test								
Time to complete	−0.233	−0.292	0.008	−0.219	−0.025	−0.169	0.007	−0.016
Overall	0.072	0.041	0.026	0.104	−0.102	−0.188	0.016	0.029
Forward	0.201	0.081	0.174	0.066	−0.101	−0.109	0.145	−0.107
Back	−0.150	0.031	−0.152	0.092	−0.029	0.009	−0.114	−0.085
Right	0.042	0.221	−0.194	−0.110	0.289	−0.047	0.289	0.032
Left	0.092	0.177	−0.083	0.009	0.045	−0.027	0.048	−0.010
Forward/Right	0.352*	0.087	0.346*	0.167	−0.237	−0.210	−0.097	−0.130
Forward/Left	0.074	−0.079	0.113	0.164	0.200	−0.148	0.191	0.196
Back/Right	0.041	−0.152	0.168	0.235	−0.035	−0.055	0.019	0.050
Back/Left	−0.079	0.130	−0.189	−0.049	−0.279	−0.305	0.040	0.117
Modified clinical test of sensory integration								
Eyes open firm	−0.037	0.101	−0.138	−0.097	0.025	0.255	−0.251	0.072
Eyes closed firm	−0.099	−0.149	−0.013	−0.019	0.270	0.228	−0.033	0.226
Eyes open foam	0.114	0.045	0.094	0.307*	0.018	−0.060	−0.068	0.050
Eyes closed foam	0.237	−0.126	0.383*	0.361*	−0.043	0.076	−0.209	−0.130
Fall risk test	0.262	0.050	0.238	0.143	0.116	−0.130	0.415*	0.260

*Spearman test. *$p<0.05$; **$p<0.01$.

group. Ageing was associated with a decline in physical performance, such as muscle strength, and static and dynamic balance, which lessened activity and increased falling risk and stability limitation (24–26). Barrett & Lichtwark (25) found that alterations in neural, muscular and tendinous parameters, and reduced capacity to recover from an imbalance episode were linked with the ageing process. Wang & Yang (27) reported that degenerative spondylolisthesis was more likely to be found among elderly people.

In addition to ageing, previous studies have also demonstrated that higher PI and PT were noted among degenerative spondylolisthesis patients (2, 8). PI was

Table IX. Odds ratio for degenerative lumbar spondylolisthesis (DLS) and low back pain and for DLS and pelvic incidence

Factor	OR (95% CI)	*p*-value
Low back pain per 1 score increase	1.49 (1.07–2.07)	0.018
Pelvic incidence per 1 degree increase	1.08 (1.02–1.15)	0.010

OR: odds ratio; 95% CI: 95% confidence interval.

Table VIII. Correlations between the spino-pelvic parameters and Quebec subscale scores in the degenerative lumbar spondylolisthesis (DLS) group ($n=45$) and non-DLS group ($n=32$)

	DLS ($n=45$)				Non-DLS ($n=32$)			
Parameters	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis	Pelvic incidence	Pelvic tilt	Sacral slope	Lumbar lordosis
Quebec1	−0.195	−0.117	−0.207	−0.262	−0.207	−0.239	0.105	0.399
Quebec2	0.172	0.091	0.010	−0.116	0.147	−0.142	0.384	0.117
Quebec3	0.078	0.076	−0.021	−0.206	−0.230	−0.075	−0.075	0.189
Quebec4	−0.111	−0.059	−0.130	−0.166	−0.214	0.083	−0.175	0.040
Quebec5	0.039	0.140	0.011	−0.241	0.004	−0.038	−0.046	−0.141
Quebec6	−0.205	0.039	−0.213	−0.218	0.004	−0.093	−0.028	0.174
Quebec7	−0.171	0.173	−0.415**	−0.345*	0.180	0.128	0.164	−0.141
Quebec8	0.013	−0.126	0.126	0.096	0.183	0.383	0.006	−0.441
Quebec9	−0.359*	−0.359*	−0.161	−0.041	0.049	0.081	0.002	−0.153
Quebec10	−0.078	0.006	−0.070	0.046	0.058	−0.078	0.334	0.203
Quebec11	0.069	0.063	−0.027	0.119	−0.117	0.210	−0.087	−0.318
Quebec12	−0.133	−0.321*	0.094	−0.053	−0.010	0.125	−0.039	0.195
Quebec13	−0.126	−0.024	−0.150	−0.133	−0.155	−0.258	0.145	0.063
Quebec14	−0.258	0.259	−0.481**	−0.462**	0.125	0.139	0.143	−0.200
Quebec15	−0.095	0.049	−0.201	−0.098	−0.042	−0.114	0.165	0.398
Quebec16	−0.253	−0.169	−0.155	−0.329*	−0.429	−0.522*	0.257	0.287
Quebec17	−0.086	−0.132	0.096	0.048	−0.117	0.041	0.011	−0.054
Quebec18	−0.198	0.061	−0.307*	−0.235	0.139	0.312	0.004	0.003
Quebec19	−0.134	0.073	−0.260	−0.263	−0.128	−0.115	0.077	0.320
Quebec20	−0.284	−0.089	−0.349*	−0.350*	−0.160	−0.350	0.181	0.221

*Spearman test. *$p<0.05$; **$p<0.01$.
*Quebec1: Get out of bed; 2: Sleep through the night; 3: Turn over in bed; 4: Ride in a car; 5: Stand up for 20-30 min; 6: Sit in a chair for several hours; 7: Climb a flight of stairs; 8: Walk a few blocks (300–400 m); 9: Walk several km; 10: Reach up to high shelves; 11: Throw a ball; 12: Run 1 block (approximately 100 m); 13: Take food out of the refrigerator; 14: Make your bed; 15: Put on socks (pantyhose); 16: Bend over to clean the bathtub; 17: Move a chair; 18: Pull or push heavy doors; 19: Carry bags of groceries; 20: Lift and carry a heavy suitcase.

a primary morphological parameter for 3-dimensional regulation of sagittal spinal curve (28, 29). It was constant after completed growth, and specific for each person (11). In contrast, SS, PT and LL are position-dependent (29). Persons with higher PI have increased risk of spondylolisthesis and greater slip grade (2, 30). Furthermore, DLS often resulted in episodic and recurrent LBP, which was the most common symptom (3, 31).

There is an anatomical difference between L4/5 and L5/S1. Ligamentous structures including the iliolumbar ligament between L4 and L5 were weaker than that between L5 and sacrum (30). In the DLS group in our study, the most common level involved was L4/L5 (57.78%), which is consistent with those of previous studies (32).

Boulay et al. (28) reported that decreased SS and flattening lordosis were noted in patients with low PI (<44°), and increased SS and prominent lordosis were found in patients with high PI (>60°). Funao et al. (30) demonstrated that PI is more strongly correlated with SS and LL than PT in the DLS group, indicating that increased SS and LL play a major compensatory role in increasing PI; in contrast, PI was more strongly correlated with PT than SS and LL among patients without DLS, indicating that pelvic retroversion plays a major compensatory role in increasing PI. Legaye et al. (11) described that, in the lateral view, the PI, SS and PT of the lumbar spine were 53.2°, 41.9° and 11.9°, respectively, for men and 48.2°, 38.2° and 10.3°, respectively, for women. Boulay et al. demonstrated that the PI, SS and PT for a healthy adult population were 53.13°, 41.18° and 11.96°, respectively, and found no significant difference between sexes with respect to PI. PI, SS and PT in the adults in Berthonnaud's study were 51.8°, 39.7° and 12.1°, respectively (33). Our results showed that the PI, SS and PT were 52.8°, 32.9° and 20.1°, respectively, for patients with DLS and 45.6°, 31.0° and 14.3°, respectively, for patients without DLS. Compared with those in the studies mentioned above, decreased SS and increased pelvic tilt were observed in our study. We only recruited patients with grade I and II DLS, and most of them had grade I DLS (88.9%). Thus, the main compensation for increased PI among non-DLS patients was pelvic retroversion. This finding is consistent with Funao et al.'s study (30). Since PI was the summation of PT and SS and was a constant variable, it was independent of pelvic spatial orientation and age after completed growth (11). When PT increased with pelvic retroversion, SS decreased.

In our DLS group, PI has a positive correlation with SS, PT and LL. In contrast, in the non-DLS group PI was associated only with PT. In the setting of sagittal malalignment, compensation to maintain an upright posture, such as pelvic retroversion, thoracic flattening, hip extension, knee flexion and ankle flexion, could be recruited to maintain a better postural stability (34). These compensatory mechanisms may correct the sagittal spino-pelvic instability and lead to better postural stability with increased pelvic tilt. Furthermore, our results showed that SS and LL also partially compensated for higher PI in patients with low-grade DLS, compared with PT only in non-DLS patients. This could explain the negative relationship between LL and QBDS. Because the risk of progression of spondylolisthesis with higher PI was compensated by LL, the disabilities that resulted from LBP were less severe. We further investigated the subscales of the QBDS. In the DLS group, PI was negatively correlated with walking several km; PT was negatively correlated with walking several km and running approximately 100 m; SS was negatively correlated with climbing a flight of stairs, making the bed, pulling or pushing heavy doors, and lifting and carrying a heavy suitcase; LL was negatively correlated with climbing a flight of stairs, making the bed, bending over to clean the bathtub, and lifting and carrying a heavy suitcase. In the non-DLS group, the PT was negatively correlated with bending over to clean the bathtub. The compensation from PT, SS and LL for PI could make these daily activities less difficult, especially for patients with DLS. For non-DLS patients, bending forward was less challenging with a more retroverted pelvis. These findings also indicate that the DLS group had greater LBP disabilities related to spino-pelvic parameters.

Although an association between PT and PI was noted in both DLS and non-DLS groups, PT was negatively correlated with SS and LL in the non-DLS group. Previous studies showed that anterior and posterior pelvic tilting led to increased and decreased LL, respectively, which was consistent with the results of our study (35).

A significant relationship between SS and LL was seen in both the DLS and non-DLS groups. DLS could lead to spinal stenosis (3, 5). Bredow disclosed that a high correlation exists between SS and LL among patients with lumbar spinal stenosis (36). The findings from the current study suggest that SS is correlated with LL among patients with lumbosacral disorder.

Higher BMI was found in patients with spondylolisthesis (8). Uysal et al. (37) revealed a positive association between PI and weight, and a negative association between PI and height. They proposed that obesity might be a risk for spondylolisthesis. Our study revealed that PI and SS have a negative relationship with height, while LL has a positive relationship with

JRM Journal of Rehabilitation Medicine JRM Journal of Rehabilitation Medicine JRM

BMI. These findings suggested that the BMI may be related to the development of spondylolisthesis through the process of hyperlordosis.

In our patients with DLS, PI was significantly correlated with limits of stability in the forward/right direction; SS was significantly correlated with limits of stability in forward/right direction and m-CTSIB scores with eyes closed on foam; LL was significantly correlated with overall and anterio-posterior index of postural stability test and m-CTSIB scores with eyes open and closed on foam. In the non-DLS group, SS was significantly correlated with risk of fall. The deterioration of postural stability in elderly people is caused by the decline in visual acuity, vestibular and somatosensory input, motor responses and sensory integration systems, and degenerative change in musculoskeletal and neuromuscular systems. All of these changes lead to impairment in sensory interactions, slowing of reaction time and decreased efficacy of protective movements. In this study, 4 different balance measurements were selected. The PS test was used to measure static postural stability via all 3 sensory inputs without interference of vision, vestibule and proprioception. The LOS test was used to evaluate the visual sensory and proprioceptive response. Fall risk was measured when the patient's proprioception was interfered with by the unstable balance platform. The m-CTSIB was used to test the stability of maintaining an upright posture under the following conditions: (*i*) EO on a firm surface (all 3 sensory inputs available); (*ii*) EC on a firm surface (visual not available; proprioceptive and vestibular available); (*iii*) EO on a dynamic surface (visual and vestibular available, proprioceptive interfered); and (*iv*) EC on a dynamic surface (visual not available; proprioceptive interfered, only vestibular available) (38).

The results show that SS has a role in the balance of both DLS and non-DLS groups. Patients with DLS with hyperlordosis have more difficulty in maintaining postural stability. Furthermore, patients with DLS with increased SS and LL found it more difficult to maintain their centre of balance and avoid body deviation while standing on foam. On an unstable surface, a hip strategy could be used. Patients with LBP might be unwilling to use a hip strategy or reluctant to make accelerations or large motions of the trunk because of fear of pain during increased trunk muscle activity (39–41). Our results found that hyperlordosis and increased SS predispose patients with DLS to imbalance on unstable surfaces, which might be related to the use of less hip strategy due to significantly greater LBP.

However, patients with DLS with higher PI and SS had fewer stability limitations and could shift their weight more rapidly and accurately during dynamic tasks in the forward/right direction, possibly related to right-handed dominance.

The multiple binary logistic regression test further showed that increases in LBP and PI were the most important factors associated with DLS.

The KUB can be used to evaluate not only the skeletal disorders (e.g. degenerative, destructive (fracture, tumour), joint inflammatory change or infection (psoas muscle)), but also the location or source of viscerogenic, gastrourinary or gynaecological diseases relevant to LBP, e.g. dyspepsia, stool retention, renal or urinary stone, or pulsatile pain due to aneurysm, etc. (42). In addition, the PI, PT, SS and LL of lateral L-S spine radiographs provide valuable information about truncal stability in both static and dynamic tasks and the subsequent impact on daily functioning.

Both DLS and non-DLS groups had impairment in balance control. SS and LL may be the partial compensation for increased PI in patients with DLS. For non-DLS patients, SS could be a predictive factor for fall risk, and a retroverted pelvis suggested less limitation in forward flexion.

Stabilization exercise or core programme could relieve back pain at rest and during active movement, and could improve active range of motion and proprioception during postural and balance control and loading task (43). Heat or electrical therapy were suggested to relieve the adverse effects of compensation, such as muscle spasm and pain disability. Flexibility exercises for the low back and hamstring muscles could relieve the flat spine or retroversion of the pelvis in non-DLS patients. Weight control was beneficial for back pain disabilities and dynamic postural stability. Furthermore, stabilization exercises help to maintain lumbar stability and motor control of lumbopevic-hip joint, especially for the patients with DLS (43, 44). Proprioceptive training and fall prevention education are recommended for both groups.

These findings suggest that the evaluation of spino-pelvic parameters, clinical characteristics, Biodex balance and QBDS are essential in patients with DLS. These measurements may assist clinicians to identify and predict spine stability and to plan more specific treatment strategies for the maintenance of spino-pelvic balance and modification of activities of daily living. This may help prevent falls for patients with non-DLS and those with low-grade DLS.

Study limitations

This study has several limitations. First, patients were recruited from a single rehabilitation centre. Secondly, the lumbosacral MRI was not evaluated, thus the incidence of spinal stenosis and its correlation with spino-pelvic parameters among our participants could not be determined. Thirdly, only patients with low-grade spondylolisthesis were enrolled, and the correlations and biomechanism of high-grade DLS could not be determined.

Conclusion

Patients with low-grade DLS were older and had significantly greater LBP, LOS, PI and PT than those without DLS. PT was the major factor compensating for both non-DLS and low-grade DLS patients. SS and LL also contributed to partial compensation for increased PI in the patients with DLS. For patients with DLS, PI and SS were significantly correlated with height. LL was significantly correlated with BMI, back pain disabilities, and stability on an unstable surface. In the non-DLS group, SS could be an indicator of fall risk. There was also a significant correlation between pelvic tilt and functional activities in both the DLS and non-DLS groups.

ACKNOWLEDGEMENTS

The authors would like to thank Andrew Wei-Hsiang Tiong for his assistance with this research.

Funding: Chang Gung Memorial Hospital, Taiwan (CMRP-G8D0911) financially supported this research (2014-3-1 to 2015-2-28).

The authors have no conflicts of interest to declare.

REFERENCES

1. He LC, Wang YX, Gong JS, Griffith JF, Zeng XJ, Kwok AW, et al. Prevalence and risk factors of lumbar spondylolisthesis in elderly Chinese men and women. Eur Radiol 2014; 24: 441–448.
2. Hresko MT, Labelle H, Roussouly P, Berthonnaud E. Classification of high-grade spondylolistheses based on pelvic version and spine balance: possible rationale for reduction. Spine (Phila Pa 1976) 2007; 32: 2208–2213.
3. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J 2008; 17: 327–335.
4. Le Huec JC, Aunoble S, Philippe L, Nicolas P. Pelvic parameters: origin and significance. Eur Spine J 2011; 20 Suppl 5: 564–571.
5. Slikker W, Lee JYB, Siemionow K, Espinoza Orias AA, An HS. Predictors of dynamic instability in degenerative spondylolisthesis. Rush Orthop J 2013: p. 13–16.
6. Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. Spine (Phila Pa 1976) 2001; 26: E243–E248.
7. Labelle H, Roussouly P, Berthonnaud E, Dimnet J, O'Brien M. The importance of spino-pelvic balance in L5-s1 developmental spondylolisthesis: a review of pertinent radiologic measurements. Spine (Phila Pa 1976) 2005; 30: S27–S34.
8. Schuller S, Charles YP, Steib JP. Sagittal spinopelvic alignment and body mass index in patients with degenerative spondylolisthesis. Eur Spine J 2011; 20: 713–719.
9. Lim JK, Kim SM. Difference of sagittal spinopelvic alignments between degenerative spondylolisthesis and isthmic spondylolisthesis. J Korean Neurosurg Soc 2013; 53: 96–101.
10. Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. Neurosurgery 2007; 61: 981–986; discussion 6.
11. Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998; 7: 99–103.
12. Morel E, Ilharreborde B, Lenoir T, Hoffmann E, Vialle R, Rillardon L, et al. Sagittal balance of the spine and degenerative spondylolisthesis. Rev Chir Orthop Reparatrice Appar Mot 2005; 91: 615–626.
13. Harrison DD, Cailliet R, Janik TJ, Troyanovich SJ, Harrison DE, Holland B. Elliptical modeling of the sagittal lumbar lordosis and segmental rotation angles as a method to discriminate between normal and low back pain subjects. J Spinal Disord 1998; 11: 430–439.
14. Habibi Z, Maleki F, Meybodi AT, Mahdavi A, Saberi H. Lumbosacral sagittal alignment in association to intervertebral disc diseases. Asian Spine J 2014; 8: 813–819.
15. Noureddin Karimi IE, Sedigheh Kahrizi, Giti Torkaman. Evaluation of postural balance using the biodex balance system in subjects with and without low back pain. Pakistan J Med Sci 2008; 24: 372–377.
16. Sherafat S, Salavati M, Ebrahimi Takamjani I, Akhbari B, Mohammadirad S, Mazaheri M, et al. Intrasession and intersession reliability of postural control in participants with and without nonspecific low back pain using the Biodex Balance System. J Manipulative Physiol Ther 2013; 36: 111–118.
17. Karimi N, Ebrahimi I, Kharizi S, Torkaman G. Reliability of postural balance evaluation using the Biodex balance system in subjects with and without low back pain. J Postgrad Med Inst (Peshawar-Pakistan) 2011; 2: 22.
18. Kopec JA, Esdaile JM, Abrahamowicz M, Abenhaim L, Wood-Dauphinee S, Lamping DL, et al. The Quebec Back Pain Disability Scale. Measurement properties. Spine (Phila Pa 1976) 1995; 20: 341–352.
19. Frontera WR. DeLisa's physical medicine and rehabilitation: principles and practice, 5th edn. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins: 2013, p. 1428.
20. Bontrager KL, Lampignano JP. Textbook of radiographic positioning and related anatomy, 8th edn. St Louis: Mosby; 2010.
21. Thomas Pope, Hans L Bloem, Javier Beltran, William B. Morrison, David John Wilson. Musculoskeletal Imaging, 2nd edn. London: Saunders, 2014, p. 1230 e3.
22. Demoulin C, Ostelo R, Knottnerus JA, Smeets RJ. Quebec Back Pain Disability Scale was responsive and showed reasonable interpretability after a multidisciplinary treatment. J Clin Epidemiol 2010; 63: 1249–1255.
23. Shirley NBMS. Biodex Balance System operation and service manual. New York; 1999.
24. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing 2006; 35 Suppl 2: ii37–ii41.
25. Barrett RS, Lichtwark GA. Effect of altering neural, muscular and tendinous factors associated with aging on balance recovery using the ankle strategy: a simulation study. J Theor Biol 2008; 254: 546–554.
26. Bergland A, Jarnlo GB, Laake K. Predictors of falls in the elderly by location. Aging Clin Exp Res 2003; 15: 43–50.
27. Wang J, Yang X. Age-related changes in the orientation of lumbar facet joints. Spine (Phila Pa 1976) 2009; 34: E596–E598.
28. Boulay C, Tardieu C, Hecquet J, Benaim C, Mouilleseaux B, Marty C, et al. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. Eur Spine J 2006; 15: 415–422.
29. Roussouly P, Pinheiro-Franco, J.L. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J 2011; 20: 609–618.
30. Funao H, Tsuji T, Hosogane N, Watanabe K, Ishii K, Nakamura M, et al. Comparative study of spinopelvic sagittal alignment between patients with and without degenerative spondylolisthesis. Eur Spine J 2012; 21: 2181–2187.

JRM Journal of Rehabilitation Medicine JRM Journal of Rehabilitation Medicine JRM

31. Herkowitz HN. Spine update. Degenerative lumbar spondylolisthesis. Spine (Phila Pa 1976) 1995; 20: 1084–1090.
32. Cifu DX. Braddom's physical medicine and rehabilitation, 5th edn. Philadelphia: Elsevier Science Health; 2015, p. 735.
33. Berthonnaud E, Dimnet J, Roussouly P, Labelle H. Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. J Spinal Disord Tech 2005; 18: 40–47.
34. Ferrero E, Ould-Slimane M, Gille O, Guigui P, French Spine S. Sagittal spinopelvic alignment in 654 degenerative spondylolisthesis. Eur Spine J 2015; 24: 1219–1227.
35. Levine D, Whittle MW. The effects of pelvic movement on lumbar lordosis in the standing position. J Orthop Sports Phys Ther 1996; 24: 130–135.
36. Bredow J, Oppermann J, Scheyerer MJ, Gundlfinger K, Neiss WF, Budde S, et al. Lumbar lordosis and sacral slope in lumbar spinal stenosis: standard values and measurement accuracy. Arch Orthop Trauma Surg 2015; 135: 607–612.
37. Uysal E, Paksoy Y, Koplay M, Nayman A, Gumus S. Effects of body mass index, mesenteric and abdominal subcutaneous adipose tissue on the spinopelvic parameters. Wien Klin Wochenschr 2015; 127: 935–941.
38. Nashner LM, Peters JF. Dynamic posturography in the diagnosis and management of dizziness and balance disorders. Neurol Clin 1990; 8: 331–349.
39. Mok NW, Brauer SG, Hodges PW. Hip strategy for balance control in quiet standing is reduced in people with low back pain. Spine (Phila Pa 1976) 2004; 29: E107–E112.
40. Radebold A, Cholewicki J, Panjabi MM, Patel TC. Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. Spine (Phila Pa 1976) 2000; 25: 947–954.
41. Henry SM, Hitt JR, Jones SL, Bunn JY. Decreased limits of stability in response to postural perturbations in subjects with low back pain. Clin Biomech (Bristol, Avon) 2006; 21: 881–892.
42. Prithvi RP. Low back pain. Medical diagnosis and comprehensive management. J Bone Joint Surg 1989; 71: 1278.
43. Kim TH, Kim EH, Cho HY. The effects of the CORE programme on pain at rest, movement-induced and secondary pain, active range of motion, and proprioception in female office workers with chronic low back pain: a randomized controlled trial. Clin Rehabil 2015; 29: 653–662.
44. O'Sullivan PB, Phyty GD, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine (Phila Pa 1976) 1997; 22: 2959–2967.

JRM Journal of Rehabilitation Medicine JRM Journal of Rehabilitation Medicine JRM