

# Pilot Case Control Study of Postural Sway and Balance Performance in Aging Adults with Degenerative Lumbar Spinal Stenosis

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## ABSTRACT

**Purpose:** Lumbar spinal stenosis (LSS), a degenerative disease encountered in adults > 65 years, is a leading cause of back and lower extremity pain, weakness, impaired sensation and balance. The purpose of this pilot study was to determine whether patients with LSS demonstrate increased postural sway and impaired balance, compared to healthy counterparts.

**Methods:** Patients with varying severity of LSS and age and gender matched controls were recruited from a tertiary care hospital, yielding 6 case-control pairs. Subjects completed generic health status (SF-36), disease specific scales (LSS) and demographic forms. Medical comorbidities were extracted from medical records. Patients received a musculoskeletal examination and performed the Functional Reach (FR) and Timed "Up & Go" (TUG) tests. Stabilogram diffusion analysis (SDA) measured center of pressure (COP).

**Results:** Patients reported moderately impaired physical function, lumbar flexibility and walked with a slightly wider base of support. TUG scores did not differ across groups. Significantly limited FR scores indicated that patients had impaired dynamic balance and were at a greater risk of falls. SDA demonstrated no significant difference in sway for patients and controls; however, patients demonstrated significantly higher critical values for antero-posterior (AP) displacement than controls.

**Conclusion:** Patients with LSS, even those with mild symptoms, demonstrate decreased function and balance, particularly in the AP direction. Physical examination measures and TUG are not ade-

quate to assess balance impairments or risk of falls in these patients. Measures such as the FR and SDA may be useful in detecting the aspects of balance impairments perceived by patients.

**Key Words:** lumbar spinal stenosis, balance, sway

## INTRODUCTION

Lumbar spinal stenosis (LSS), a degenerative disease encountered in older adults, is a leading cause of low back pain (LBP) and lower extremity pain in people aged 65 years and older.<sup>1</sup> The prevalence of LSS is high.<sup>2-4</sup> The American Association of Neurological Surgeons and the Congress of Neurological Surgeons have postulated that 400,000 Americans, most over 60 years of age, are presently suffering from degenerative LSS.<sup>4</sup> Pain and claudication are primary symptoms and lead to decreased walking capacity, function, and may impact balance.<sup>5,6</sup>

Degenerative LSS is commonly seen at the L4-L5 and L5-S1 segments.<sup>5,7,8</sup> Patients typically present with LBP, lower extremity pain, and neurogenic claudications which are exacerbated by lumbar extension and relieved with lumbar flexion. Sensory and proprioceptive changes due to lumbar nerve root involvement are believed to cause pain and balance problems; leading to decreased walking capacity and function.<sup>6,9</sup> Patients with LSS also have impaired spinal proprioception, potentially leading to increased postural sway and risk of falls.<sup>10,11</sup>

Balance may be assessed using clinical and technological measures, such as force plate analysis.<sup>12</sup> Collins and De Luca<sup>13</sup> proposed a method of assessing center-of-pressure (COP) displacement during quiet stance called stabilogram-diffusion analysis (SDA).<sup>13</sup> Stabilogram-diffusion analysis uses the statistical-mechanical approach, plotting COP displacement against time to obtain diffusion plots. Consequently, SDA demonstrates that COP displacement may be divided into 2 distinct parts: the short-term region and the long-term region.<sup>13,14</sup> During the short-term phase, the COP tends to move away from a point of equilibrium, implying activity of the open-loop system. The open-loop system is thought to correspond to the 'steady-state' activity in postural muscles resulting from descending commands or muscle activity occurring spontaneously at the spinal cord level; it does not use sensory feedback mechanisms.<sup>13,14</sup> During the long-term phase, the COP tends to return to equilibrium due to the stabilizing strategies from the closed-loop system.<sup>13,14</sup> The closed-loop system, on the other hand, operates using sensory feedback<sup>13,14</sup> and requires interaction of the visual, vestibular, proprioceptive, and somatosensory systems with the central nervous system.

Few studies quantify balance in patients with LSS or explore the association between postural sway and clinical balance measures.<sup>12,15</sup> Researchers<sup>8,16</sup> report an inconsistency

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in pathology, clinical signs, function, and patients' self report, which complicates choosing and interpreting tests. Decreased balance occurs with aging; however, no studies have explored the proportion of balance impairments attributed to LSS and not in combination with aging.

## METHODS

This cross sectional, pilot case-control study assessed postural sway and clinical balance performance in patients with LSS and in healthy adults. We recruited patients from a tertiary care spine center, with varying degrees of clinically significant LSS. The inclusion criteria for patients were: (1) physician confirmed diagnosis of symptomatic LSS; (2) back, buttock, and/or leg pain exacerbated by spinal extension; (3) no history of spinal surgery within the last year; (4) no epidural steroid injection within the past 6 months. Healthy adults were selected as controls from the hospital's Arthritis Center Registry. All cases were matched with their controls based on age ( $\pm 2$  years) and gender. Controls were excluded if they had any pre-existing low back conditions or pain. Cases and controls were excluded if they had: (1) visual, auditory and vestibular impairments or history of vertigo; (2) co-morbidities affecting balance or function, such as diabetes, neuropathy, vertigo or other lower extremity pathology; (3) history of lower extremity surgery or cardiovascular, neurological, or metabolic disorder; (4) cognitive impairments and language difficulties. Nine cases and 4 controls met the inclusion and exclusion criteria. Of these 6 cases and 3 age and gender matched controls were used to yield a 2:1<sup>17</sup> matching ratio and analysis was performed on 6 case-control pairs. In most cases, the subjects were matched on their co-morbidities. This project was reviewed and approved by the hospital's Institutional Review Board and all subjects provided informed consent.

All subjects completed a demographic questionnaire including fall history items, and the Medical Outcomes Survey Short-Form 36 (SF-36) physical function subscale. The SF-36 is an overall health related quality of life questionnaire with high internal consistency (Cronbach's alpha  $>0.80$ ),<sup>18</sup> good test-retest reliability (ICC  $>0.80$ )<sup>19</sup> and good concurrent validity ( $r = 0.71$ ). The responsiveness of the SF-36 physical function scale in patients with LBP is 0.72.<sup>20</sup> Comorbidities were assessed using the Cumulative Illness Rating Scale (CIRS), a chart based measure has good concurrent validity ( $r = 0.73-0.84$ ) in detecting co-morbidities in geriatric populations and good inter-rater reliability (ICC = 0.78-0.81).<sup>21,22</sup>

Cases completed the LSS questionnaire, a disease specific measure developed by Stucki et al<sup>23,24</sup> that consists of 2 subscales: LSS symptom severity and physical function. The LSS symptom severity subscale contains 7 items with a 5-point Likert response, addressing impairments and back and lower extremity symptom severity. Items are added and averaged to yield a final score ranging from 1-5, with higher scores indicating increased severity. The disease-specific function scale contains 6 questions that focus on walking distance, ability to walk for pleasure, and ability to walk to and from the bedroom/bathroom and uses a 4-point Likert scale. Again scores are summed and averaged across items, to yield an interval value, with higher scores indicating decreased function. The LSS subscales

demonstrate good to excellent internal consistency (Cronbach's alpha = 0.82-0.90) and responsiveness (0.96-1.07).<sup>24</sup>

A licensed physical therapist with 20 years of musculoskeletal experience, blinded to diagnosis, conducted a physical examination for each subject. The exam consisted of visual posture assessment, deep tendon reflexes, vibratory and pin-prick sensations, lower extremity muscle strength, and lumbar spine flexibility on all subjects. Pin-prick and vibratory sensation of the first metatarsal, medial malleoli, and lateral malleoli were tested since they correspond to L4 and L5 nerve roots that are commonly affected by LSS.<sup>25-27</sup> Vibratory sensation was measured using a 128 Hz tuning fork and categorized based on the criteria described by Schwartz<sup>25</sup> as either intact, diminished, or absent. Lumbar range of motion (ROM) was measured using the Schober's test for lumbar flexion and extension. The intra-rater reliability of the Schober's test for flexion varies from average to good (ICC ranging from 0.71-0.96)<sup>27-29</sup> and for lumbar extension is good (ICCs between 0.90-0.95).<sup>28</sup> A hand held dynamometer (Nicholas Hand Held Dynamometer®, Model 00160 Nicholas Lafayette Instrument, Atlanta, GA) was used to measure muscle force production of hip abductors, flexors, extensors, knee flexors and extensors using the "make test." The inter-rater reliability of this technique is high (ICC 0.81-0.92).<sup>30</sup> Ankle strength was assessed using manual muscle testing techniques. The Chaffin lift – a standardized test where a subject pulls at a crossbar from a hole tapped in the floor was used to assess back extensor strength.<sup>31</sup> The examination included straight leg raise (SLR) and Faber's tests to rule out other low back, sacroiliac joint, and hip joint pathology.<sup>32</sup> Pain was measured by the Visual Analogue Scale (VAS). The Lumbar Quadrant test, a provocation test that causes reproduction of symptoms due to narrowing of the intervertebral foramen,<sup>28,32</sup> was conducted for cases and controls to assess the presence, if any, of peripheralization of symptoms.

Stance width was measured with subjects standing in a normal relaxed stance. The point of the mid-heel, mid-foot, and the head of the first metatarsal were marked with a tape, measured, and averaged to obtain values of stance-width. Step width was measured using a 6 ft long walking pad (Stepwise® Walking Pad, Sportime, Atlanta, GA). This pad traced the outline of the feet as they made contact with the pad surface. Subjects walked at their normal pace for 10 feet using a 4 ft lead before walking across the 6 ft walking pad. Perpendicular distances between forward progression line from the point of initial contact of the right and left heels were averaged over each stride to determine the step width.<sup>33,34</sup>

Stabilogram diffusion analysis, a highly sensitive measure of quantifying balance,<sup>13</sup> was performed using a computerized force plate. The reliability of short term diffusion analysis is 0.76–0.92, while the reliability of long-term analysis is 0.59–0.83.<sup>13,14</sup> Stabilogram diffusion analysis was conducted on all subjects. Subjects were instructed to stand on a force plate, barefoot, and in their usual stance, with arms at their side and eyes open for a period of 30 seconds. The distance between great toes, medial arches, and heels was obtained from the stance width measurement. Subjects were instructed to remain as still as possible while the displacement of the COP was measured using an AMTI (American Medical Technologies, Watertown,

MA) force plate. The analogue signals from the force plate were converted to digital images for analysis using an analogue-to-digital converter. A sampling frequency of 1000 Hz was used for data collection and conversion. Data were obtained for 10, 30 second trials. For the SDA, the short-term diffusion constant ( $D_s$ )—corresponding to the open-loop system—and the long-term diffusion coefficient ( $D_l$ )—corresponding to the closed-loop system— were calculated for medio-lateral (M-L) ( $D_{xs}$ ,  $D_{xl}$ ), A-P ( $D_{ys}$ ,  $D_{yl}$ ) and planar directions ( $D_{rs}$ ,  $D_{rl}$ ).

Subjects performed the TUG, a measure functional mobility and fall risk,<sup>35,36</sup> and FR<sup>37</sup> a measure of fall risk. The validity of the TUG in detecting community dwelling elders' risk of fall ranges from 0.61-0.87 in.<sup>35,36</sup> The TUG has excellent intra-rater and test- retest reliability with ICCs of 0.96-0.99 and 0.94-0.98, respectively.<sup>36,38</sup> The TUG was performed following the standardized protocol described by Podsaldio and Shumway-Cook.<sup>35,36</sup> Patients wore regular footwear and could use the assistance of the arms of the chair to rise and their usual assistive devices, if any, during testing. Functional reach (FR), measure of functional balance, was conducted according to the protocol described by Duncan et al<sup>37</sup> to measure the maximum displacement of the subjects' reach in centimeters. The sensitivity of the FR in detecting risk of falls is 0.76, while the specificity is 0.34. The test-retest reliability of the FR test is high, with ICC = 0.89.<sup>37,39</sup>

### Statistical Analysis

The analysis of the COP parameters was conducted using customized programs in MATLAB Mathworks, Natick, MA). Descriptive statistics were calculated for all variables to describe the sample. Paired *t*-tests were conducted on case-control pairs to determine the paired difference between specific physical examination measures, TUG, FR, and SDA data. SPSS version 14.0 was used for statistical analyses.<sup>40</sup> The level of significance was adjusted to 0.01 for the *t*-tests for multiple testing. Power was calculated since the sample size was small.

### RESULTS

The mean age of the case-control pairs was 67.4 years (SD=6.1). Four case-control pairs (66%) were females. Eight of the 9 subjects were Caucasians and 1 was Hispanic. The average number of systems affected by co-morbidities was nearly identical for the cases and controls, 3.5 and 3, respectively. The data presented in Table 1 indicate that cases had varying duration and severity of LSS. Four cases (44%) experienced LBP for more than a year, 3 (33%) were classified as chronic cases having pain for more than 3 years, and 2 (22%) were recently diagnosed with LSS. Cases reported a large range of pain (1.16 to 7.67; mean<sub>VAS</sub>=2.9) and disease specific symptom severity scores [1.14 (mild) to 3 (severe); median of 2.22]. Disease specific function scores showed that most cases could function with some pain (Mean<sub>LSS</sub> = 2.2; Median<sub>LSS</sub> = 2.2; range = 1.2 – 2.75). Two cases reported a history of near falls in the past 6 months, though none experienced a fall. However, 4 case subjects (67%) did report problems with balance over the past month (Table 2). General physical function differed greatly between cases and controls [mean<sub>cases</sub> = 50 (SD=25.5), mean<sub>controls</sub> = 90 (SD=15.5); *p*=0.017].

All cases demonstrated pain with lumbar pain provocation procedure-lumbar extension in standing for 30 seconds. However, 4 cases (66%) reported symptoms on either side during the quadrant test; 3 cases (50%) having positive quadrant test, experienced pain with lumbar lateral flexion. No cases had a positive SLR and 1 control had a positive SLR bilaterally. However, the specificity of SLR is poor (pooled specificity = 0.26)<sup>41</sup> and degenerative changes in the lumbar spine that occur with aging can yield positive SLR results. Five cases (83%) had abnormal reflexes, out of which 3 (50%) had diminished Achilles reflexes and 2 demonstrated diminished patellar reflexes (Table 2). One case had brisk ankle and knee reflexes. Sensory examination over the medial and lateral malleoli and the first 1<sup>st</sup> space revealed that only 1 case had decreased sensation over the left first web space, while the malleoli

**Table 1. Pain at Rest and with Provocation Tests for Patients with LSS & Controls**

	Visual Analogue Scale (VAS)	Duration of symptoms	LSS Symptom Severity Scale	Lateral lumbar flexion (in extension)	On lumbar extension & rotation (in standing)	Standing Lumbar Extension (with Pelvis supported)	Straight Leg Raise	Hip/SI Joint Pain
<b>Case 1</b>	1.23	1-3 yrs	1.71	–	+ (L)	Back pain	–	–
<b>Control 1</b>	0	–	-	–	–	–	–	–
<b>Case 2</b>	1.16	> 3 yrs	2.92	+ (L)	+ (Both)	Back pain	–	+ (Both)
<b>Control 2</b>	0	–	-	–	–	–	–	–
<b>Case 3</b>	7.67	1-3 yrs	2	–	–	Back pain	–	–
<b>Control 3</b>	0.07	–	-	–	–	–	+ (Both)	–
<b>Case 4</b>	2.33	Not available	1.14	–	–	Back pain	–	–
<b>Control 4</b>	0	–	-	–	–	–	–	–
<b>Case 5</b>	1.3	1-3 yrs	3	+ (R)	+ (Both)	Back pain	–	–
<b>Control 5</b>	0	–	-	–	–	–	–	–
<b>Case 6</b>	3.42	> 3 yrs	2.43	+ (R)	+ (R)	Radiating to thigh	–	–
<b>Control 6</b>	0.07	–	-	–	–	–	+ (Both)	–

– : Negative result; +:Positive result

**Table 2. Scores of Function and Self Report in Patients with LSS & Controls**

	H/o Near Falls	Comorbidities (CIRS score)	LSS Physical Function	SF-36 Physical Function	Timed "Up & Go" (sec)	Functional Reach (cms)
Case 1	-	5	1.2	75	7.3	13.46
Control 1	-	3	1	70	9.08	25
Case 2	+	10	2.6	25	7.33	12.49
Control 2	-	4	1.2	100	6.38	25.68
Case 3	-	5	1.4	60	9	21.83
Control 3	-	2	1	100	6.31	32.33
Case 4	-	2	2	50	8.93	25
Control 4	-	3	1	70	9.08	25
Case 5	+	4	2.4	15	11.29	19.9
Control 5	-	4	1.2	100	6.38	25.58
Case 6	-	2	2.75	75	6.04	23.5
Control 6	-	2	1	100	6.31	32.33

CIRS: Cumulative Illness Rating Scale

had normal sensations. This individual had long-standing disease, as well as diminished ankle and knee reflexes. Among the controls, 1 individual demonstrated decreased sensation over the left 1st web space and right medial malleolus with no changes in reflexes.

Cases demonstrated limited lumbar ROM compared to controls, as measured by the Schober's test. The mean flexion was 3.16 cm (SD = 1.1) and 4.33 cm (SD = 1), respectively. The mean lumbar extension among patients was also less compared to controls (Mean<sub>LEcases</sub> = 2 cm (SD=1.2), Mean<sub>LEcontrols</sub> = 3.2 (SD=0.9); 95% CI = -0.4 to -2.1 ; p = 0.019) (Table 3).

Lower extremity and back strength did not significantly differ between cases and controls. The lowest force generated by a control was 15.4 N, who also demonstrated hyper-reflexia and long-standing

**Table 3. Physical Examination Findings for Patients with LSS & Controls**

	Posture	Schober test (cm)	Lumbar Extension (cm)	REFLEXES		SENSATION			STRENGTH (Newtons)			
				Knee Jerk	Ankle Jerk	LM	MM	1st web space	Knee Extensor	Knee Flexor	Stance Width (cm)	Step Width (cm)
Case 1	Stooped	2.5	1.5	+	+	N	N	N	22.15	13.35	8	10.5
Control 1	N	3	2	++	++	N	N	N	18.15	12.15	18.73	4.3
Case 2	Flat	4	4.5	+	+	N	N	⊗ (L)	14.2	6.65	18.3	12.46
Control 2	N	5	4	++	++	N	N	N	16.45	10.4	11.66	2.6
Case 3	Flat	3	1.5	++	++	N	N	N	17.35	9.75	11.16	6.33
Control 3	N	5	3.5	++	++	N	N	N	24.83	14.85	14.3	7
Case 4	Flat	2	1	+	++	N	N	N	20.1	16.5	17	8.7
Control 4	N	3	2	++	++	N	N	N	18.15	12.15	18.73	4.3
Case 5	Stooped	2.5	2	-	-	N	N	N	20.6	10.05	20	8.35
Control 5	N	5	4	++	++	N	⊗ (R)	⊗ (L)	16.45	10.4	11.66	2.6
Case 6	Hyper	5	1.5	+++	+++	N	N	N	...	...	9.8	8.93
Control 6	N	5	3.5	++	++	N	N	N	24.83	14.85	14.3	7

LM: Lateral Malleolus; MM: Medial Malleolus; N: Normal; -: Absent; +: Diminished; ++: Normal; +++: Brisk; ⊗: Decreased; (R): Right; (L): Left

symptoms (Table 3). Back extensor strength was almost equal for cases and controls, which is not surprising as LSS is known to affect the peripheral muscles more than the trunk. The mean back extensor strength of the cases was 54 N (SD=40.8) and that of the controls was 60.7 N (SD=9.3).

Step width assessment in relaxed standing revealed an interesting finding (Table 3). Controls stood with a slightly wider base of support (mean=14.9, SD=3.2) as compared to the cases (mean=14, SD=5); both of which are greater than the normative value of 8.1 cm.<sup>33,34</sup> However, the cases, whose mean step width was 9.21 cm (SD=2.1) walked with significantly wider

steps than the controls, whose mean was 4.63 cm (SD=1.9). These findings indicate that the cases had poorer balance than the controls during gait (95% CI =0.75 to 8.4; p = 0.013). Table 4 discusses the clinical significance of physical examination and function scores.

**Functional Balance and Sway**

The TUG results did not differ significantly between cases and controls [mean<sub>TUGcontrols</sub> = 8.3 s (SD=1.8) and mean<sub>TUGcases</sub> = 7.2 s (SD=1.4); p=0.16] (Table 4). However, cases demonstrated a significantly limited FR in the A-P direction compared to controls

**Table 4. Means and Clinical Significance of Physical Examination and Function**

Physical Examination	Mean (Cases)	Mean (Controls)	p value (95% Confidence interval)	Clinical Significance
Schober's Flexion	3.2 cm	4.3 cm	0.013 (-2.14 to -0.18)	4 cm
Schober's Extension	2.0 cm	3.2 cm	0.018 (-2.25 to -0.08)	2.5 cm
Quadriceps Strength	18.9 N	19.8 N	0.48 (-6.07 to 6.22)	-
Hamstrings Strength	11.2 N	12.4 N	0.34 (-5.45 to 3.99)	-
Lift Force	54.0 N	60.7 N	0.40 (-54.14 to 45.22)	-
Stance Width	14.04 cm	14.89 cm	0.39 (-8.38 to 6.67)	6.7 cm
Step Width	9.21 cm	4.63 cm	0.013 (0.75 to 8.41)	8.0 cm
Function	Mean (Cases)	Mean (Controls)	p value (95% Confidence interval)	Clinical Significance
SF-36 Physical Function	50	90	0.017 (-3.95 to -76.07)	69.38*
Functional Reach Test*	19.4 cm	27.7 cm	0.004 (-13.34 to -3.47)	25 cm†
Timed "Up & Go" Test	8.3 sec	7.3 sec	0.16 (-1.45 to 3.57)	14 sec‡

\*Significant at 0.01; \*\*MCID; †Clinical Cut-off; N: Newtons

995% CI = -3.3 to - 13.3; p = 0.004). The mean FR distance was 19.4 cm (SD=5.4) for cases and the mean for controls was 27.7 cm (SD=3.6).

Stabilogram diffusion analysis analysis of short-term region demonstrated that the cases had greater sway than controls in the A-P, M-L, and the planar directions (Table 5). However,

**Table 5. Comparison of Stabilogram Diffusion Parameters in Patients with LSS and Healthy Adults**

	Cases (Mean)	Controls (Mean)	95% Confidence Interval	p value
<b>Short term region</b>				
Dxs	0.11	0.07	-1.05 to 1.7	0.23
Dys	0.20	0.12	0.00 to 0.15	0.03
Drs	0.31	0.24	-0.10 to 0.38	0.08
<b>Long Term Region</b>				
Dxl	0.01	0.01	-0.02 to 0.01	0.25
Dyl	0.01	0.01	-0.03 to 0.02	0.3
Drl	0.03	0.02	-0.08 to 0.06	0.35
<b>Critical Time</b>				
Dxt	1.41	1.31	-1.48 to 2.01	0.3
Dyt	1.17	0.98	-0.33 to 0.7	0.19
Drt	1.03	0.82	-0.11 to 0.40	0.07
<b>Critical Value (Distance)</b>				
Dxv	0.26	0.17	-0.38 to 0.69	0.2
Dyv*	0.31	0.13	0.04 to 0.31	0.01
Drv	0.49	0.25	-0.22 to 0.87	0.07

\*Significant at 0.01  
**Dxs:** short-term diffusion coefficient for x-axis; **Dys:** short-term diffusion coefficient for y-axis; **Drs:** planar short-term diffusion coefficient; **Dxl:** long-term diffusion coefficient for x-axis; **Dyl:** long-term diffusion coefficient for y-axis; **Drl:** planar long-term diffusion coefficient; **Dxt:** critical time for x-axis; **Dyt:** critical time for y-axis; **Drt:** critical time for planar displacement; **Dxv:** critical value for x-axis; **Dyv:** critical time for y-axis; **Drv:** critical time for planar displacement

these differences were not statistically significant. Similar results were obtained for sway parameters in the long-term region. The critical point, which refers to the point where patients change from the open loop to the closed-loop system, showed a significant difference in the A-P direction [mean  $D_{YVcases} = 0.31$  (SD=0.20), mean  $D_{YVcontrols} = 0.13$  (SD=0.11); 95% CI= 0.04 - 0.31; p=0.01]. This implies that patients detect movement only after larger displacement and take longer to switch from spontaneous activity to the feedback system. However, this pattern was not seen in medio-lateral or planar directions.

Based on the results, effect size index and power were calculated (Table 6). The power of this study varied from 2% (step width) to 77% (FR), that is, from low to moderate for most results. However, most of the effect size indices ranged from 0.97 to 1.73 representing excellent effect sizes, indicating low power was due to small sample.

**Table 6. Effect Size & Power Analysis for Physical Exam, Function, and SDA Parameters**

Variable	Effect Size Index	Power	% Power
SF-36 Physical Function	1.16	0.41	41%
Schober's Flexion	1.25	0.47	47%
Schober's Extension	1.13	0.38	38%
Back extensor strength	0.11	0.02	2%
Stance width	0.12	0.02	2%
Step Width	1.26	0.47	47%
Functional Reach*	1.73	0.77	77%
Timed "Up and Go"	0.44	0.07	7%
M-L Sway (Dxl)	0.38	0.12	12%
A-P Sway (Dyl)	0.97	0.29	29%
Critical Value*	1.37	0.55	55%

\* Significant at 0.01  
**Dxl:** long-term diffusion coefficient for x-axis;  
**Dyl:** long-term diffusion coefficient for y-axis

**DISCUSSION**

Our aim was to determine whether patients with LSS demonstrated increased postural sway and reduced balance performance compared to healthy adults. Differences in FR performance and SDA critical value, suggest that the patients in our sample demonstrate balance impairments, particularly in A-P direction. We accounted for the effect of aging on balance and postural sway by using matching in our design. Therefore, we conclude that age did not account for the differences in test performance between cases and controls in this study. Differences in A-P sway and balance were expected as the primary pathology of LSS and resultant chronic postural changes occur in the A-P direction. Our findings

are consistent with previous studies of older adults and patients with chronic LBP which report impaired balance in persons with degenerative diseases or chronic LBP.<sup>14,42,43</sup>

Our results demonstrate that patients with LSS have increased sway, and significantly higher SDA critical values, indicating they require a greater distance to sense movement and employ the closed-loop system. Increased displacement before activation of the closed-loop system may occur due to many reasons.<sup>14,42,43</sup> As suggested by Collins<sup>14</sup> and Laughton,<sup>42</sup> degenerative changes increase lower extremity postural muscle activity, typically in the hamstrings and soleus, in response to a chronic flexed posture.<sup>14,42</sup> Peterka<sup>45</sup> hypothesized that forces which restore the body to normal alignment may be impaired due to muscle weakness leading to increased sway in the short-term region. Another possible explanation may be that the time taken to sense COP displacement, transmit these impulses, and process the output may be delayed in patients with LSS<sup>42,44</sup> as a result of decreased muscle spindle sensitivity or decreased nerve conduction velocity.<sup>42,44,46</sup> In support of this assertion, we found that 83% of patients with LSS demonstrated abnormal reflexes while no controls had abnormal reflexes. Further studies using electromyography and nerve conduction velocity are needed to confirm these findings in patients with LSS and determine whether changes in muscle activity causes increased sway or whether muscle activity changes in response to increased sway.

Researchers have indicated that increase in M-L sway increases the risk of falls.<sup>42,47</sup> In our sample, patients with LSS stood and walked with a wider BOS, suggesting that compensatory strategies are used to overcome balance deficits. However, our patients did not have increased M-L sway. We may have failed to detect changes in M-L direction since the subjects were asked to stand on the force-plate with their 'normal stance' and tended to stand with a wider BOS, which may have masked the increase in M-L sway.

From the negative results of the sensory and motor assessment, we can say that balance impairments in both the open-loop and closed-loop may occur without clinically detectable changes in sensations and muscle strength. Balance may be affected due to a combination of subclinical decreases in back and lower extremity strength, as well as various aspects of the somatosensory functions, such as minimal decreases in proprioception and kinesthesia at ankle, hip, or lumbar spine, indicating that minimal degenerative changes in the lumbar spine may impair balance.

Patients with LSS reported poorer physical function than controls. However, we do not know the degree to which pain, decreased balance, or other impairments contribute to functional decline. Functional mobility of the patients may not be affected over a short distance. Literature suggests that functional mobility and balance may decrease due to various factors beyond balance such as pain and claudication.<sup>5,6,8,16</sup> Consequently, the TUG does not appear to be a sensitive measure of functional mobility or the risk of falls. Moreover, the TUG does not consider the quality of gait such as a wider BOS.

Performance on FR, a measure of functional balance in the A-P direction, indicated that patients with LSS had a significantly limited reach than their healthy counterparts. Moreover, patients with LSS demonstrated FR scores below 25 cm, the clinical threshold for high risk of falls.<sup>47,48</sup> This result is supported by the SDA data. Patients with LSS demonstrate greater impairments in the sagittal plane as a result of the disease process and corresponding chronic

flexed posture, causing a decrease in functional balance in the A-P direction.<sup>5,7,8</sup> Therefore, the FR test may be a useful, quick, and simple clinical tool to screen patients with LSS for risk of falls and should be further validated in this population.

A primary limitation of our study was a small sample size. It was challenging to obtain subjects older than 65 years of age who had no documented co-morbidities affecting balance or function such as diabetes, neuropathy, vertigo, or who had not undergone lower extremity surgeries. The small sample size may have lead to a Type II error and impacted our ability to detect changes on measures of balance such as the diffusion constants. However, even with reduced power we were able to identify significant differences between cases and controls. Second, our sample included patients with different degrees of disease severity, including very mild to severe disease. We may have detected more changes if we sampled patients with only moderate to severe disease. We could not obtain an objective measurement of ankle strength using dynamometry. Therefore, we may have missed some subtle changes in ankle force and corresponding associations between ankle force production and postural sway and balance, as ankle weakness is found with lumbar root involvement.<sup>5,8,15</sup> We used well validated clinical and self-report measures as well as SDA to detect balance impairments and fall risk in this study. A large trial may validate the use of balance performance measures in place of expensive lab measures and decrease the cost of patient care.

## CONCLUSION

In conclusion, patients with LSS have poorer balance, particularly in the A-P direction, and decreased function secondary to disease process, even with minimal impairments. Balance should not be overlooked in patients with LSS. Physical examination measures and the TUG are not adequate to assess balance impairments or risk of falls. Additional measures such as SDA may assist in detecting aspects of balance that are perceived by patients but not commonly detected by balance performance measures. Functional reach may be able to assess fall risk in this sample. Other clinical tests that correlate with sensitive measures such as SDA should be validated in patients with LSS to reduce the cost of patient care.

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