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## Clinical Studies

Assessment of standing balance in normal versus cervical spondylotic myelopathy patients<sup>☆</sup>Mikhail Lew Perez Ver, Jeffrey L. Gum, Steven D. Glassman, Leah Y. Carreon<sup>\*</sup>

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## A B S T R A C T

**Background:** The Romberg test is used to identify balance issues in patients with Cervical Spondylotic Myelopathy (CSM), but has subjective interpretation. The purpose of this study is to evaluate force plate pressure readings during a Romberg test to quantify postural control.

**Methods:** Quantitative Romberg force plate readings with eyes open and closed in patients with CSM were obtained and changes in balance measurements were compared to a normal population ( $N = 28$ , mean age  $39 \pm 7$  years).

**Results:** We identified 30 CSM patients with a mean age of  $58 \pm 10$  years. Majority of patients presented with pain (90%) and neurologic symptoms (83%). Cord compression on imaging was identified in 90%. Mean eyes closed Romberg measurements were larger compared to eyes open measurements in CSM patients ( $p < 0.01$ ). There was a larger change in Romberg ( $\Delta R$ ) measurements in CSM compared to normals for total sway area (TSA,  $14.18$  vs  $0.02$  cm<sup>2</sup>,  $p < 0.001$ ) and average speed (AS,  $2.07$  vs  $0.23$  cm/s,  $p < 0.001$ ). The presence of long tract signs produced larger  $\Delta R$  (TSA,  $15.35$  vs  $0.02$  cm<sup>2</sup>,  $p = 0.003$ ; AS,  $2.21$  vs  $0.23$  cm/s,  $p = 0.001$ ), and those with identified cord compression on imaging also had larger  $\Delta R$  (TSA,  $15.1$  vs  $0.02$  cm<sup>2</sup>,  $p < 0.001$ ; AS,  $2.17$  vs  $0.23$  cm/s,  $p < 0.001$ ).

**Conclusions:** Standing balance can be quantified in patients with CSM and is worse when compared to a normal population. Long tract signs and cord compression in imaging translates to worse balance in myelopathic patients. The use of quantitative Romberg measurements help evaluate balance in CSM.

## Introduction

Loss of balance control is a common clinical symptom in patients with cervical myelopathy, manifesting as difficulty in maintaining posture and normal gait [1–6]. Balance is achieved through central nervous system synthesis via three main afferents: (1) proprioception and joint positioning, (2) visual input and (3) vestibulocochlear systems. Failure of one of these systems can lead to the loss of overall balance [7]. Cord compression involving the posterior dorsal column leads to dysfunction of vibration sense, deep touch, proprioception, and joint positioning [1–3]. This signal impairment clinically manifests with the body's poor balance control, increased body sway and inability to maintain a steady gait [8].

Only a few studies have objectively measured balance control mechanisms in myelopathic patients [3,6,9]. The Romberg test evaluates the somatosensory, visual and vestibulocochlear systems for balance control by testing if there is an increased sway or loss of balance when the patient stands still with eyes open and eyes closed [10–12]. However, this test is qualitative, only allows findings of “normal” or “abnormal”, and can have a subjective interpretation. Performing the Romberg test on a force plate permits an objective measure of balance and Center of Pressure (CoP) sway.

Surgical treatment of cervical myelopathy relies on the correlation of radiographic and clinical severity. Timely intervention limits progression of disease, avoids permanent cord injury, and prevents secondary injury from falls or other trauma [13–16]. This study aims to establish the use of quantitative Romberg measurements in quantifying standing balance control with respect to disease symptomatology and imaging findings in cervical myelopathy. Non-invasive force plate data provides a quantified measure of standing imbalance which can help grade severity, assess risk for falling, and guide treatment. Additionally, if we are able to quantify imbalance in myelopathy, more optimally timed intervention could potentially allow for improved surgical outcomes especially in ambiguous and equivocal cases.

## Methods

This retrospective cross-sectional study was approved by the Institutional Review Board of the University of Louisville. Patients seen at the Norton Leatherman Spine Center for cervical spondylotic myelopathy from 2016 to 2017 were identified. Patients presenting with symptoms and examination findings consistent with myelopathy who had quantitative Romberg measurements were included in this study. Patients without magnetic resonance imaging (MRI) or computed tomography myelograms (CT-M) were excluded.

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**Fig. 1.** Quantitative balance assessment while performing a modified Romberg examination on a force plate using the Diers Pedoscan System.

Patients were stratified into those with or without long tract signs on physical exam such as abnormal extremity reflexes, Hoffman's and/or a clinical Romberg test were placed in the cohort with long tract signs. A second stratification was done dividing the patients with and without cord compression on MRI or CT Myelograms, and cord signal changes on T2 weighted MRI.

Quantitative Romberg measurements were taken using a force plate device from the Diers Pedoscan (Diers Biomedical Systems, Germany) system. The examination was performed by a physical therapist and typically takes a few minutes to perform. This system evaluates abnormal pressure and imbalance by measuring the center of pressure (COP) from force distributions on the force plate. Standing Romberg measurements where feet are planted together and modified with arms raised forward for a period of 30 s were taken twice - one measured with eyes open and the next with eyes closed, as per protocol (Fig. 1). Several parameters were retrieved for analysis: [1] total lateral movement (cm), or the total lateral distance traveled left and right; [2] total anterior-posterior movement (cm), or the total distance traveled in an antero-posterior direction; [3] total sway area (cm<sup>2</sup>), which is the total surface area covered by the subject's COP movement; [4] mean velocity (cm/s), or the speed at which the subject moved to correct their posture; and [5] mean frequency (Hz), which measures how often the subjects adjusted their position during the exam (Fig. 2). Linear regression was performed to identify any correlation with advancing age from the individual parameters. The degree of balance control was defined as the difference in quantitative Romberg data from eyes open and eyes closed exams ( $\Delta R$ ) for each balance parameter measured. The  $\Delta R$  was compared to a database of normal volunteers who participated in a balance evaluation study at the Rosalind Franklin University of Medicine and Science (Glinski A, Henry M. *Romberg Revisited: An Evaluation of Balance using the Diers Pedoscan System*. Rosalind Franklin University of Medicine and Science; 2015). Use of the database was obtained with permission and the oldest population subset with a mean age of 37.82  $\pm$  7.16 years (30–52) was used ( $N = 28$ ). The normal population was asymptomatic from a cervical spine perspective and had no medical comorbidities.

**Table 1**  
Demographics of myelopathic patients with quantitative Romberg data.

Demographics ( $N = 30$ )		Values
Age, mean $\pm$ SD		58.40 $\pm$ 9.59
Sex	Male, N (%)	14 (47%)
	Female, N (%)	16 (53%)
Height (m), mean $\pm$ SD		1.69 $\pm$ 0.12
Weight (kg), mean $\pm$ SD		89.10 $\pm$ 21.99
Body Mass Index, mean $\pm$ SD		30.82 $\pm$ 5.56
Charlson Comorbidity Index, mean $\pm$ SD		2.27 $\pm$ 1.80
Neck Disability Index, mean $\pm$ SD		38.23 $\pm$ 18.81
History,	Fall	3 (10%)
N	Visual Impairment	6 (20%)
(%)	Vestibular Disease	2 (7%)
	Neurogenic Disease	0 (0%)

**Table 2**  
Examination and imaging findings of myelopathic patient data.

Findings ( $N = 30$ )		Count (%)
Exam, N (%)	Axial Pain	23 (77%)
	Radicular Pain	23 (77%)
	Motor Weakness	19 (63%)
	Sensory Deficits	6 (20%)
	Long Tract Signs	6 (20%)
	Hoffman	10 (33%)
	Clinical Romberg	9 (30%)
Imaging, N (%)	Cord Compression	27 (90%)
	Cord Signal Changes	6 (20%)

Datasets were compiled and analyzed using IBM SPSS for Macintosh, Version 25 (IBM Corp., Armonk, N.Y., USA). Paired samples *t*-test and independent samples *t*-test were performed to determine significant changes within the eyes open and closed exams, and between the myelopathic and normal group. The myelopathic patients were subcategorized to those with [1] positive long tract signs, [2] cord compression on imaging, and [3] T2 cord signal changes, and were compared to a normal subset. Binomial regression analysis was done to determine any association of changes in  $\Delta R$  total sway area with all patient sub-groups particularly to identify any relationship with increasing change in sway area. Similarly, linear regression analysis was performed on  $\Delta R$  total sway area with available patient reported outcome measures.

## Results

We identified 30 patients evaluated for cervical spondylotic myelopathy (CSM) who required treatment. These patients had quantitative balance measurements recorded preoperatively. Baseline demographics are summarized in Table 1. There were 14 males and 16 females, with a mean age of 58  $\pm$  10 years, BMI of 30.8  $\pm$  5.6 kg/m<sup>2</sup>, Charlson Comorbidity Index of 2.3  $\pm$  1.8, and Neck Disability Index (NDI) 38.23%  $\pm$  18.81%. On review of medical histories, 20% had visual impairment where majority had myopia, and 7% had a previous history of vertigo; none had identified or diagnosed neurodegenerative disease. Cervical stenosis causing myelopathic symptoms were mainly due to cervical spondylosis (27, 90%), while the remainder was caused either by diffuse idiopathic skeletal hyperostosis (1, 3%), adjacent segment degeneration (1, 3%), or ossified posterior longitudinal ligament (1, 3%). Majority of the patients had cervical pain and neurologic symptoms (Table 2). Among those who had neurologic symptoms 53% had significant exam findings for long tract abnormalities. Review of imaging findings based on the radiologist's impression and treating surgeon's interpretation, showed 90% with cord compression, and 20% with cord signal changes on T2 weighted imaging (Table 2).

Quantitative Romberg measurements for CSM patients are listed in Table 3, while the normal control group is presented in Table 4. Both the myelopathic and normal literature control group had significant differences between eyes open and eyes closed measurements in all balance

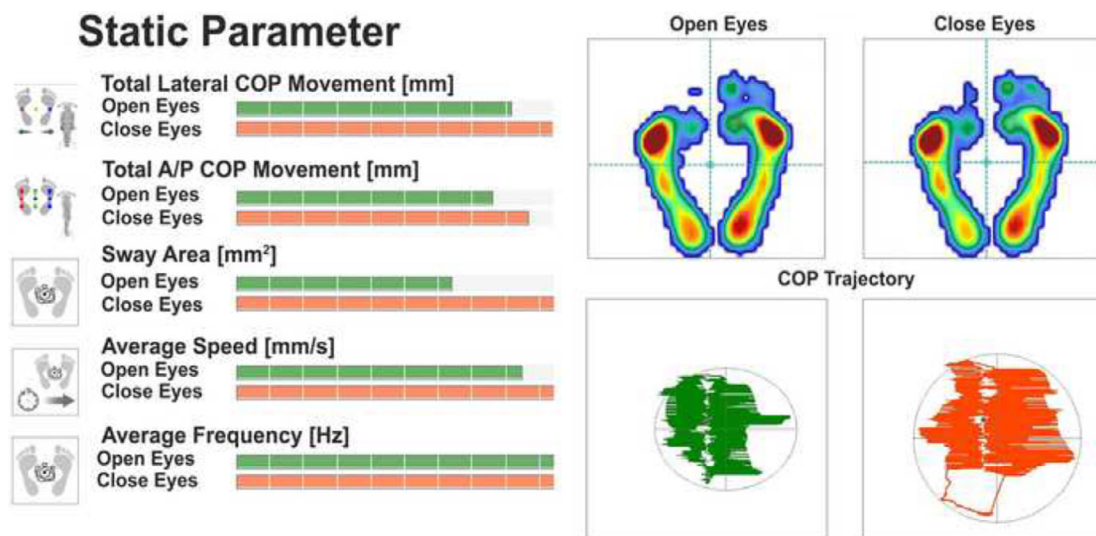


Fig. 2. Graphical representation of quantitative balance parameters measured during eyes open and eyes closed Romberg exams.

**Table 3**  
Quantitative balance measurements from eyes open & eyes closed Romberg test in patient sample group.

CSM Patients	Open	Closed	p-value	ΔR	r <sup>2</sup> for Age
Total Lateral COP (cm)	45.99 ± 25.53	55.92 ± 44.88	0.000	39.93 ± 39.33	0.007
Total AP COP (cm)	44.25 ± 18.76	52.81 ± 44.39	0.000	38.55 ± 32.73	0.018
Total Sway Area (cm <sup>2</sup> )	12.22 ± 13.62	26.40 ± 20.60	0.000	14.18 ± 15.56	0.000
Average Speed (cm/s)	2.36 ± 1.10	4.43 ± 2.20	0.000	2.07 ± 1.79	0.010
Average Frequency (Hz)	5.58 ± 1.20	15.54 ± 1.13	0.492	-0.04 ± 0.30	0.000

parameters using paired samples *t*-test. The computed ΔR, or change in eyes open and eyes closed exams, for both groups were not associated with advancing age based on linear regression analysis ( $r^2 < 0.2$ ) (Tables 3 and 4).

The degree of balance control seen on ΔR measurements for each parameter was analyzed into different subpopulations which were compared to the normal control individually (Table 5). Patients seen and treated for myelopathy had larger differences in total sway area and average speed ( $p < 0.001$ ) compared to the normal control. The same is true for patients presenting with long tract signs on physical examination ( $p < 0.05$ ) and those with documented cord compression on imaging ( $p < 0.001$ ). Evidence of cord signal changes on T2 weighted imaging did not show any difference compared to the normal control except for average speed ( $p = 0.047$ ). Binomial regression analysis using ΔR of total sway area showed 1.45 odds of having CSM ( $r^2 = 0.58, p = 0.001$  [95% CI 1.17–1.80]), 1.40 odds of having cord compression ( $r^2 = 0.58, p = 0.001$  [95% CI 1.14–1.71]), and 1.37 odds of having long tract signs ( $r^2 = 0.58, p = 0.003$  [95% CI 1.11–1.69]), for every point increase in ΔR. An increasing ΔR for total sway indicates a larger increase in the difference between the eyes-open and eyes-closed standing balance exam which translates to worsening balance control. There were no as-

sociations of ΔR total sway area with T2 cord signal changes ( $r^2 = 0.13, p > 0.05$ ). Pilot analysis for functional outcome scores, and its association with balance measures using linear regression, showed significantly worsening NDI scores increasing by 0.64 for each point increase in ΔR of total sway area ( $r^2 = 0.28, p = 0.005$  [95% CI 0.21–1.07]).

**Discussion**

Cervical myelopathy is often characterized by impaired standing balance and unstable gait [4, 16, 21]. This may be a direct effect of cord compression over the dorsal columns, which transmit fibers for proprioception and joint position sense [1–3,17]. Poor static balance control and increase in body sway results from this compression [3,6,17]. Testing proprioceptive ability in patients with cervical myelopathy as a function of knee position sense has been first described by Takayama et al. establishing the relationship of proprioception loss with deteriorating balance in myelopathy [2]. In addition, maintenance of balance may be affected by compression of the efferent motor system, leading to an inadequate reactive muscular control and overall muscular weakness and fatigue [17–20]. Ultimately, the pathology of cord compression creates an unfavorable environment for the maintenance of balance in posture and gait that results in the clinical myelopathic picture [5,17,21,22–25].

Quantification of the Romberg test was obtained from the total distances travelled in a lateral and anteroposterior direction from both open and closed eye exams. This creates a “sway area” as the center of pressure travel is recorded and used as a surrogate measure of balance. When combined with temporal measurements, the speed and frequency of balance correction can be obtained as well. Emphasis was placed on the total sway area, and the average speed and frequency of correction since it correlates directly to body sway and its response to balance control [3,6,10].

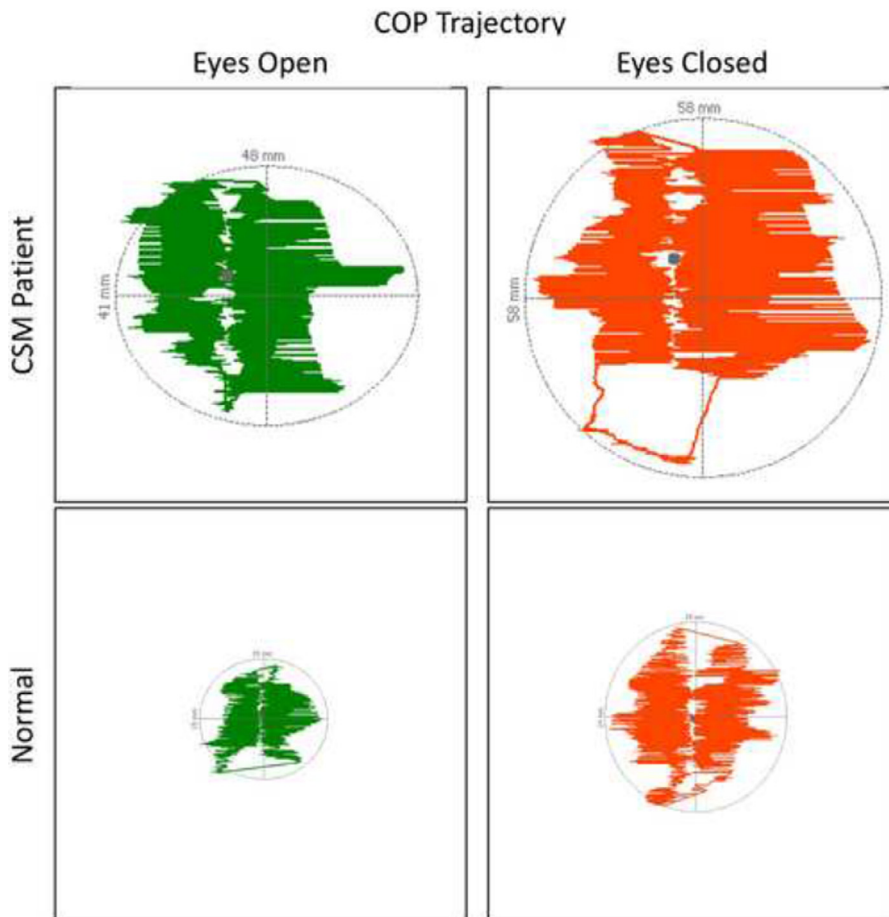
**Table 4**  
Quantitative balance measurements from eyes open & eyes closed Romberg test in normal control group.

Normal Population*	Open	Closed	p-value	ΔR	r <sup>2</sup> for Age
Total Lateral COP (cm)	103.56 ± 63.57	105.78 ± 57.98	0.882	2.22 ± 78.34	0.079
Total AP COP (cm)	311.04 ± 146.44	356.97 ± 157.72	0.102	45.93 ± 143.74	0.356
Total Sway Area (cm <sup>2</sup> )	0.06 ± 0.03	0.07 ± 0.04	0.022	0.02 ± 0.04	0.192
Average Speed (cm/s)	0.88 ± 0.15	1.11 ± 0.26	0.000	0.23 ± 0.25	0.210
Average Frequency (Hz)	0.69 ± 0.23	0.75 ± 0.22	0.163	0.06 ± 0.23	0.158

\* N = 28, mean age 37.82 ± 7.16 (30–52).

**Table 5**  
Difference in mean change of Quantitative Romberg exams within different subgroups compared to normal control.

Parameters	Mean Change in Eyes Open and Eyes Closed Romberg ( $\Delta R$ )									
	Normal (N = 28)		CSM Patients		Cord Compression		T2 Cord Signal Changes		Long Tract Signs	
			(N = 30)	p-value	(N = 27)	p-value	(N = 6)	p-value	(N = 16)	p-value
Total Lateral COP (cm)	2.22	39.93	0.027	42.46	0.021	19.63	0.289	42.95	0.026	
Total Lateral AP (cm)	45.93	38.55	0.793	40.23	0.840	15.66	0.285	39.06	0.812	
Total Sway Area (cm <sup>2</sup> )	0.02	14.18	0.000	15.1	0.000	3.17	0.498	15.35	0.003	
Average Speed (cm/s)	0.23	2.07	0.000	2.17	0.000	0.98	0.047	2.21	0.001	
Average Frequency (Hz)	0.06	-0.04	0.159	-0.02	0.267	-0.06	0.596	-0.06	0.196	



**Fig. 3.** COP trajectory and total sway area comparison in myelopathic and normal groups.

Age related decline in postural balance measured from Romberg examinations are confounded with different factors involving degenerative changes from systems involved in balance control [7,18]. The interplay of these factors should be scrutinized in evaluating Romberg tests, and specific causes for loss of balance should be sought. Our results have shown direct effects of myelopathy on balance and a negligible association with age having  $r^2$  values  $< 0.2$ , in the background of normal vestibular and upper motor neuron function (Tables 3 and 4). This supports findings of Anson et al., where they showed proprioceptive function as a major determinant to postural sway irrespective of age [8].

We found that there are significant differences in the measured parameters of total lateral center of pressure distance, total sway area and average speed between the myelopathic patient population compared to the normal literature control and this is consistent with earlier reports (Fig. 3) [3]. This highlights the pathological effects of myelopathy on proprioception, resulting to further loss of balance with the closed eye exam. However, our method of Romberg testing with arms extended forward may have resulted to increased anteroposterior distances travelled

in both the myelopathic and normal groups. The similarity in the average frequency establishes that both groups correct postural imbalance the same number of times when visual input is removed from the closed eye exam. They differ based on the average speed, with the myelopathic group having faster speeds of balance correction compared to normals. These higher velocities translate to a larger amount of effort required to quickly counter this imbalance in myelopathic patients, whereas slow rocking movements in normal patients require less effort. Our results show an agreement with findings of Yoshikawa et al. [3] and Tanashima et al. [1,2] having obtained larger values for measured body sway in myelopathic patients compared to a normal population.

Going further, we have established the utility of quantitative Romberg measurements in differentiating the normal control from those with positive long tract signs, and those with cord compression seen on imaging studies. There is a significantly larger difference in total sway area and speed of correction on each group analysis of patients with positive long tract signs, and cord compression on imaging, when compared to normals. Use of objective body sway measurements can help



delineate patients presenting with these findings. These objective and reproducible measurements can potentially help guide surgical decision making in the future. It has been well-documented that earlier intervention with cord decompression results in improved outcomes [14,26–28].

Analysis for mean differences in the open and closed eye exams ( $\Delta R$ ) in patients with T2 weighted cord signal changes did not show any statistical difference from the normal control. Not all patients seen for myelopathy have cord signal changes, yet they present with poor balance control. This may be explained simply as an effect of cord compression. On the other hand, cord signal changes occur with prolonged cord compression and can basically be interpreted as a measure of time. Based on these results, considering the small sample size and nature of this cross-sectional study, it can be inferred with caution that poor balance control occurs with the presence of cord compression. While balance, in relation to prolonged symptoms based on cord signal changes, can possibly improve. Compensatory mechanisms counteracting severe imbalance in patients with myelomalacia may have already set in leading to balance measurements not significantly different to the normal control. Increasing the sample size and determining balance longitudinally with respect to time, may further ascertain the effects of myelomalacia and prolonged symptoms on balance control. Additionally, myelomalacia, especially T1 cord signal change has been repeatedly shown to correlate with poorer post-operative outcomes and thus potentially a better proxy for duration of cord compression instead of dysfunction [26,29–31]. If further analysis confirms this finding, this objective measure could lead to earlier surgical intervention prior to development of cord signal change, and ultimately better outcomes.

Based on regression analysis, the use of total sway area as a surrogate measure of balance and body sway showed significant associations with symptomatic myelopathy ( $r^2 = 0.58$ ), cord compression on imaging ( $r^2 = 0.58$ ), and long tract signs ( $r^2 = 0.58$ ). Every point increase in the difference between eyes open and eyes closed Romberg exams ( $\Delta R$ ), which translates to worsening balance control, showed increasing odds for having symptomatic myelopathy (1.47x), cord compression on imaging (1.40x) and long tract signs on examination (1.37x). Romberg force plate data provides a measurable output of standing balance which is associated with CSM. Quantitative balance measurements provide a scale to which dichotomous findings of compression on imaging and long tract signs on examination can be graded and possibly compared. These associations statistically substantiate the use of quantitative Romberg tests as a measure of imbalance in myelopathy [17]. This is also supported by our pilot sub-analysis which showed that an increasing change in total sway area is associated with worsening NDI scores, despite having relatively weak associations ( $r^2 = 0.28$ ,  $p = 0.005$ ). Worse patient reported outcomes are expected with poor balance based on increasing  $\Delta R$  measurements seen in myelopathic patients. Quantifying balance provides an objective tool which can differentiate symptomatic myelopathy and possibly guide surgical decision making, with the potential for instituting earlier treatment in patients who have no clear cut indications based on clinical symptoms and imaging findings.

There are limitations to this retrospective pilot study. The limited sample size for patient groups who had quantitative Romberg readings and use of a literature control may have underpowered the analysis. Ideally regression analysis should be done with a large population, but despite this, significant associations were revealed with the limited sample size, which highlights a significant effect of symptomatic myelopathy and cord compression with standing balance control. The study may be improved if there were aged-match comparisons among groups. Better associations and more substantial conclusions can be derived from regression analysis once larger sample sizes on stratified data are available. We have established that objective Romberg measurements can quantify balance, but the utility of quantitative balance as a diagnostic test can be appreciated with better controls and larger sample sizes using receiver operating characteristic curve analysis. Using only a force plate and not a full gait analysis with motion capture does not assess kinematics data needed for compensation analysis. A force plate may

not be available in clinics, limiting the generalizability of the results of the study. Well validated classification systems identifying the degree of myelopathy were not used to compare with the obtained balance measurements. Identifying associations with these classification systems is an important area of future research to better assess the predictive ability of quantitative balance measurements in determining disease severity. The measurements on preoperative patients limited its value in assessment of postoperative treatment outcomes, but this is also a topic of future research.

In conclusion, we have verified earlier published work on balance measurement in myelopathy. Static balance can be reliably quantified in patients with myelopathy using force plate Romberg measurements. The quantitative balance measurements are worse in patients with cervical spondylotic myelopathy, cord compression on imaging, and long tract signs on examination. They have larger differences between open and closed eye Romberg exams compared to a normal population. Increasing differences in Romberg exams are significantly associated with increased odds of having symptomatic myelopathy, cord compression on imaging and long tract signs on examination, as well as worsening NDI scores. The use of quantitative Romberg exams can be used to quantify balance in myelopathy. Objective balance measurements may help guide surgical decision making in CSM management. Further studies on balance determination in postoperatively treated CSM patients may be beneficial in evaluating progression and monitoring for clinical recovery.

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#### Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.nxsj.2020.100023](https://doi.org/10.1016/j.nxsj.2020.100023).

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