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Which Neuromuscular Attributes are Associated with Changes in Mobility among Community-dwelling Older Adults with Symptomatic Lumbar Spinal Stenosis?

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Abstract

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The manuscript listed below includes similar information about patient characteristics at baseline. The submitting manuscript differs on several factors including the objectives, outcome measures, and methods.

Objectives: To identify neuromuscular attributes associated with mobility and changes in mobility over two years of follow-up among patients with and without SLSS.

Design: Secondary analysis of a longitudinal cohort study.

Setting: Outpatient rehabilitation center.

Participants: Community-dwelling older adults ≥ 65 years with self-reported mobility limitations. SLSS was determined using self-reported symptoms of neurogenic claudication and imaging-detected lumbar spinal stenosis.

Interventions: Not applicable.

Main Outcome Measure: Basic and advanced mobility as measured by the Late-life Function and Disability Instrument (LLFDI).

Results: Among 430 community-dwelling older adults 54 (13%) patients met criteria for SLSS while 246 (57%) did not. On average LLFDI basic and advanced mobility scores decreased significantly from baseline through year two for participants with SLSS (basic: $p=0.04$, 95% CI 0.18, 5.21; advanced $p=0.03$, 95% CI 0.39, 7.84). Trunk extensor muscle endurance (trunk endurance) and leg strength were associated with baseline basic mobility ($R^2=0.27$, $p<0.001$) while leg strength and knee flexion ROM were associated with baseline advanced mobility among participants with SLSS ($R^2=0.47$, $p<0.001$). Among participants without SLSS trunk endurance, leg strength and ankle ROM were associated with baseline basic mobility ($R^2=0.38$, $p<0.001$) while trunk endurance, leg strength, leg strength asymmetry, and knee flexion ROM were associated with advanced mobility ($R^2=0.20$, $p<0.001$). Trunk endurance and leg strength were associated with change in basic mobility ($R^2=0.29$, $p<0.001$) while trunk endurance and knee flexion ROM were associated with change in advanced mobility ($R^2=0.42$, $p<0.001$) among participants with SLSS. Among participants without SLSS trunk endurance, leg strength, knee flexion ROM and ankle ROM were associated with change in basic mobility ($R^2=0.22$, $p<0.001$) while trunk endurance, leg strength and knee flexion ROM were associated with change in advanced mobility ($R^2=0.36$, $p<0.001$).

Conclusions: Patients with SLSS experience greater impairment in the neuromuscular attributes: trunk endurance, leg strength, leg strength asymmetry, knee flexion and extension ROM, and ankle ROM compared to patients without SLSS. Differences exist in the neuromuscular attributes associated with mobility at baseline and decline in mobility over two years of follow-up for patients with and without SLSS. These findings may help guide rehabilitative care approaches for patients with SLSS.

Keywords

aged; spinal stenosis; mobility limitation

Approximately 25% of adults aged ≥ 70 years experience mobility limitations including difficulty walking.¹ Walking performance commonly worsens with aging and more so for older adults with symptomatic lumbar spinal stenosis (SLSS).^{2–5} SLSS has a prevalence of 10–14% and is the most frequent indication for spinal surgery in patients aged ≥ 65 years.^{6, 7} Evaluating the factors that may be associated with mobility is important to understand among patients with SLSS.

Physical therapy (PT) is often recommended for patients with SLSS.⁸ Optimizing rehabilitation with the most effective interventions is a necessity given the current focus on both time-efficient and cost-effective care.⁹ Practice guidelines support active PT approaches for patients with SLSS.⁸ The International Classification of Functioning, Disability and Health and Treatment/Enablement theories, support interventions that target body system impairments contributing to improved functional mobility.^{8, 10–14} However, the optimal design of rehabilitation interventions targeting mobility limitations remains unclear for patients with SLSS.¹⁵ While the associations between neuromuscular attributes (body system impairments), and mobility have been studied among older adults in general, these relationships may differ among older adults with SLSS. Limited studies suggest that trunk extensor muscle endurance (trunk endurance), leg strength and leg ROM limitations are greater and advanced mobility skills are more difficult for older patients with SLSS.¹⁶ However, previous work included small sample sizes, limited mobility outcomes to walking measures without addressing mobility tasks and did not evaluate long-term relationships between neuromuscular attributes and mobility tasks.^{2–5, 16, 17} Studying the relationship between a broader range of neuromuscular attributes and a more comprehensive measure of mobility among older adults with SLSS can contribute to filling knowledge gaps and guide the development of more targeted, evidence-based rehabilitation interventions for patients with SLSS.

The Boston Rehabilitative Study of the Elderly (Boston RISE) evaluated a large set of neuromuscular attributes amenable to rehabilitative care and linked to the performance of mobility tasks among community-dwelling older adults.^{18, 19} Mobility, the primary outcome of Boston RISE, was evaluated using a well-validated, patient-reported measure of lower extremity function that encompasses a broad spectrum of mobility tasks.²⁰ Boston RISE also contains a questionnaire that defined the clinical symptoms of SLSS. Previous studies evaluating participants with SLSS from the Boston RISE cohort identified relationships for the neuromuscular attributes: trunk endurance, leg speed, leg strength, leg strength asymmetry, knee extension asymmetry and knee ROM with performance based mobility.¹⁷ These findings are consistent with studies evaluating older adults in general.^{19, 21} Patients with SLSS experience mobility limitations more so than patients without SLSS and we hypothesize that unique associations between neuromuscular attributes and self-reported mobility will be present.¹⁶ However, the relationship of neuromuscular attributes to self-reported mobility has not been studied over time for patients with SLSS. Therefore, to address the aforementioned knowledge gaps regarding impairment-mobility relationships among SLSS patients, a secondary analysis of the Boston RISE was conducted.

This study aimed to compare which neuromuscular attributes are (1) associated with self-reported mobility at baseline and (2) predictive of a decrease in mobility over two years of follow-up among community-dwelling older adults with and without SLSS. We hypothesized that impairment of neuromuscular attributes: trunk endurance, leg strength, leg speed and knee flexion ROM would be associated with mobility at baseline and with a reduction in mobility over 2 years of follow-up among community-dwelling older adults with SLSS.

Methods

Boston RISE is a prospective cohort study of 430 community-dwelling older adults ≥ 65 years who are at risk for mobility decline, as defined by self-reported difficulty or inability to walk one-half mile and/or climb one flight of stairs without assistance.¹⁸ The main study included annual assessments of neuromuscular attributes, self-reported and performance-based measures of mobility and the presence of neurogenic claudication, the hallmark symptom characterizing SLSS, across 2 years of follow-up.²²

Inclusion criteria for the Boston RISE were: age ≥ 65 years, ability to speak and understand English, receiving primary care from a partnering healthcare provider at the time of the study, difficulty or inability to walk one-half mile and/or climb one flight of stairs, no planned major surgery, and no planned move from the area for two years. Exclusion criteria included significant visual impairment, uncontrolled hypertension, lower extremity amputation, supplemental oxygen use, myocardial infarction or major surgery in the previous 6 months, Mini-Mental State Examination score <18²³, and a Short Physical Performance Battery score <4²⁴. Boston RISE and this secondary analysis received approval from the Spaulding Rehabilitation Network Institutional Review Board.

Participants

For inclusion in this secondary analysis participants must have completed a 7-item spinal stenosis questionnaire at one of three annual visits (baseline, year 1 or year 2).²² This questionnaire assessed symptoms related to neurogenic claudication: pain, numbness or weakness in either leg, aggravated with walking and reduced with trunk flexion postures. This questionnaire has a high diagnostic accuracy for detecting the clinical syndrome of lumbar spinal stenosis (LSS) (LR, 3.7; 95% CI, 2.9–4.8).²² In addition, participants must have completed annual measures of neuromuscular attributes and mobility.

SLSS was defined using symptoms of neurogenic claudication and spinal imaging demonstrating imaging-detected LSS. Cross-sectional spinal imaging was not part of the primary study but was gathered from two separate sources. First, the electronic medical record (EMR) was accessed to abstract either computed tomography (CT) or magnetic resonance imaging (MRI) reports identifying the presence of LSS. Imaging reports were interpreted by the primary author (C.T.S.). Since the diagnosis of SLSS requires both, a characteristic clinical presentation and confirmation of lumbar spinal canal narrowing, only medical records of participants with neurogenic claudication symptoms were reviewed for imaging-detected LSS.^{22, 25} LSS severity was classified from none to critical using an 8-point Likert scale for spinal levels from T12 through S1. Based on the high prevalence of mild-moderate lumbar spinal stenosis in asymptomatic older adults²², imaging-detected LSS was defined as the presence of moderate-severe central canal stenosis, or severe neuroforaminal stenosis. Lateral recess stenosis was not recorded for this analysis due to poor reliability in previous studies and a lack of consensus on optimal grading.²⁶ Imaging that occurred >5 years prior to or >3 years following self-reported neurogenic claudication symptoms was excluded.²⁷ An inter-rater reliability study for abstraction of imaging-detected LSS was conducted in support of these methods (Kappa statistic=0.87; 95% agreement). The second source of evidence for imaging-detected spinal stenosis was

retrieved from a separate ancillary study of Boston RISE conducted for a different scientific purpose.²⁸ Within that study lumbar spine CT scans for 50 participants of Boston RISE were read by a spine physiatrist trained in the assessment of lumbar spine imaging for research purposes (P.S.). CT scans identifying moderate-severe central canal stenosis or severe neuroforaminal stenosis were used for this analysis.²⁸

Using the LSS questionnaire and information abstracted from the EMR and/or CT scans two separate categories were defined (Figure 1). Participants with neurogenic claudication symptoms from at least one of three annual visits and imaging-detected LSS were classified as *SLSS*. Participants reporting no neurogenic claudication at all three time points were classified as *No SLSS*. Participants with neurogenic claudication symptoms but without imaging evidence or a severity of LSS that did not meet study criteria were excluded from this study.

Baseline demographics of age, gender, and education were evaluated along with selected health factors. The number of comorbidities (0–13) was ascertained from a validated questionnaire and included the following: heart disease, high blood pressure, diabetes, stomach disease, kidney disease, liver disease, blood disorders, cancer, depression, osteoarthritis, back pain, and rheumatoid arthritis.²⁹ Body Mass Index (BMI) was calculated as weight/height² (kg/m²).³⁰ The Mini-Mental State Examination (0–30) measured cognitive status with lower scores indicating worse cognitive performance.²³ Global pain was evaluated using the Brief Pain Inventory Pain Severity Subscale (0–10). This subscale is an average of 4 pain ratings: pain at its worst in the last week, at its least in the last week, on average, and at its current status.³¹

Neuromuscular Attributes

Ten neuromuscular attributes from Boston RISE were selected for analysis: trunk endurance; leg strength; leg strength asymmetry; leg speed; knee flexion range of motion (ROM); knee flexion ROM asymmetry; knee extension ROM; knee extension ROM asymmetry; ankle ROM; and kyphosis.¹⁸ These neuromuscular attributes represent body structure impairments that are amenable to rehabilitation and associated with mobility for older adults.^{17, 19, 21} Trunk endurance was measured using a specialized plinth that stabilized the participant's pelvis 45 degrees from horizontal. Endurance was recorded as the time in seconds (0–150) that a participant could maintain a neutral trunk position with arms crossed over his/her chest.³² Leg strength and leg speed were measured using a pneumatic leg press. The 1-repetition maximum was determined for both lower extremities. The higher value of either lower extremity (right or left) was recorded and normalized by body weight (Newtons/kilogram). Leg speed (m/s) was measured as the speed of movement derived from the participant's measurement of maximum leg power (speed=power/force).¹⁹ Leg strength asymmetry was measured as the ratio of the leg with greater strength divided by the leg with less strength. Lower extremity ROM was measured using a goniometer based on standardized protocols.³³ Maximum knee flexion and extension ROM (degrees) were recorded with the participant in supine. Knee flexion and extension ROM asymmetry were recorded as the absolute difference between the right and left ROM measures. Impaired ankle ROM was recorded as the inability to dorsiflex to 0 degrees, or the inability to

plantarflex >20 degrees on side. Kyphosis was measured with the patient standing. A flexicurve ruler was placed over the participant's thoracic spine from C7 to the lumbo-sacral junction. The resulting curvature of the ruler was traced onto a paper and a measure of height/length $\times 100$ was recorded based on methods previously described.³⁴

Mobility Outcome

Self-reported mobility was evaluated using the Late-life Function and Disability Instrument (LLFDI) previously described.³⁵ Within the LLFDI mobility tasks are categorized into 3 domains: upper extremity function, basic lower extremity function (basic mobility) and advanced lower extremity function (advanced mobility). Analyses included basic and advanced mobility, which best correspond to lower extremity mobility tasks. Basic mobility tasks included stepping off a curb, standing up from a low couch and getting into and out of a car. Advanced mobility tasks included climbing stairs while carrying an object and getting up from the floor. Each domain is calibrated on a 0–100 scale with higher scores indicating better mobility.

Statistical Analysis

Boston RISE studied patients across 4 years of follow-up. For our study, baseline measures of neuromuscular attributes and mobility were derived from the annual visit that occurred closest to the referent imaging report or CT scan for participants with SLSS. Change in mobility was measured from the newly established baseline up through two years of follow-up. For instance, when radiologic LSS was identified at the primary study's year-two time point (baseline), year three (one year of follow-up) and four (two years of follow-up) measures of mobility were used to evaluate change in mobility. Measures of neuromuscular attributes for the No SLSS group were analyzed from the earliest annual visit when no neurogenic claudication was reported. Weighted imputation, an approach advocated for addressing missing data among studies of older adults was used for missing neuromuscular attributes.³⁶

Summary statistics were calculated using means with standard deviations for continuous variables and frequencies with percentages for categorical variables for participants with and without SLSS. All variables were evaluated for normality. Paired t-tests were used to evaluate within-group mean differences for basic and advanced mobility from baseline to the year two follow-up for participants with and without SLSS. Between-group mean changes in basic and advanced mobility from baseline to the year two follow-up were evaluated using analysis of variance comparing participants with SLSS to those without SLSS. Assumptions were evaluated using the F test. To evaluate the association of neuromuscular attributes with baseline mobility two multivariable regression models were created for each group. One model was created for each outcome, basic and advanced mobility, accordingly. After evaluating neuromuscular attributes for collinearity, the bivariate associations of neuromuscular attributes with the mobility outcomes were evaluated. Neuromuscular attributes with an association of $p < 0.1$ with the outcome were included in initial regression models. Then, neuromuscular attributes that met inclusion criteria were included within a multivariable linear regression model to determine their relationship with basic mobility and then advanced mobility. Using manual backward selection the neuromuscular attribute with

the largest p-value was removed from the model and this process was continued until all neuromuscular attributes had p-values <0.05 . Adjustment variables were selected based on their association with the outcomes. Adjustment variables that were statistically significant, changed the beta coefficient $>20\%$, or had strong clinical relevance remained in the final model. Fit statistics were evaluated to ensure that the statistical assumptions for each multivariable linear regression model were met.

To evaluate the association of neuromuscular attributes with change in mobility among those with and without SLSS, two mixed effects regression models were created for each outcome, basic mobility and advanced mobility. Change in the outcome was evaluated as an interaction between the neuromuscular attributes and time. The same iterative process used in creating the multivariable linear regression models was used for the mixed effects regression models. EMR data was collected using REDCap.³⁷ SAS 9.4 and STATA 14.1 were used for statistical analyses.

Results

Among 430 Boston RISE participants, 176 (41%) reported the presence of neurogenic claudication symptoms, 246 (57%) did not have neurogenic claudication symptoms and 8 (0.02%) participants had missing LSS questionnaires (Figure 1). Among those who reported the presence of neurogenic claudication 54 (31%) met criteria for SLSS, 246 (57%) were classified as No SLSS, and 122 (69%) did not meet criteria for imaging-detected LSS and were excluded.

On average community-dwelling older adults with SLSS were aged 76.9 (± 6.6) years and mostly female (67%). Participants with SLSS experienced more comorbidities, higher BMI, and greater global pain compared to participants without SLSS (Table 1). The number of participants with post high school education was significantly less among patients with SLSS compared to those without SLSS. Participants with SLSS experienced greater impairment in trunk endurance, leg strength, leg strength asymmetry, knee flexion ROM, knee extension ROM and ankle ROM compared to those without SLSS (Table 1). On average LLFDI basic and advanced mobility scores decreased significantly from baseline through year two for participants with SLSS (Table 2). Participants without SLSS experienced a statistically significant decrease in advanced mobility from baseline through year two (Table 2). There were no between-group differences in basic (SLSS 2.70 $\pm$ 8.68, No SLSS 1.05 $\pm$ 12.28, $p=0.38$) or advanced mobility (SLSS 4.11 $\pm$ 12.84, No SLSS 3.25 $\pm$ 10.38, $p=0.62$) for participants with SLSS compared to those without SLSS across two years of follow-up.

Multivariable linear regression models evaluating the neuromuscular attributes associated with baseline mobility among participants with and without SLSS are within Table 3. All models were adjusted for age and gender. Additional adjustment variables, number of comorbidities and BMI did not meet criteria for inclusion into the models. Among participants with SLSS trunk endurance and leg strength explained 27% of the variance ($R^2 = 0.27$) for basic mobility. The inclusion of ankle ROM for participants without SLSS explained a stronger relationship ($R^2 = 0.38$) for basic mobility. Among participants with

SLSS leg strength and knee flexion ROM explained a moderate level of variance ($R^2 = 0.47$) for advanced mobility. Trunk endurance, leg strength, leg strength asymmetry and knee flexion ROM accounted for a small amount of variance ($R^2 = 0.20$) for advanced mobility among participants without SLSS.

Mixed effects regression models showed significant changes in basic and advanced mobility over two years of follow-up among participants with SLSS (Table 4). Among participants without SLSS a significant change in advanced mobility over time was also identified (Table 4). Trunk endurance and leg strength explained a small amount of the variance ($R^2 = 0.29$) for change in basic mobility among participants with SLSS. Among participants without SLSS trunk endurance, leg strength, knee flexion ROM and ankle ROM explained 22% of the variance ($R^2 = 0.22$) for change in basic mobility. A moderately strong association ($R^2 = 0.42$) occurred with trunk endurance and knee flexion ROM for change in advanced mobility among participants with SLSS. Among participants without SLSS trunk endurance, knee flexion ROM and leg strength accounted for 36% of the variance ($R^2 = 0.36$) for the change in advanced mobility.

Discussion

This secondary analysis of community-dwelling older adults with SLSS who are at risk for mobility decline identified that impairment in 3 neuromuscular attributes: trunk endurance, leg strength, and knee flexion ROM, are associated with a decline in a broad range of basic and advanced mobility tasks. Similarly, impairment in the neuromuscular attributes associated with mobility among patients without SLSS includes: trunk endurance, leg strength, and knee flexion ROM, as well as ankle ROM and leg strength asymmetry. Overall the strength of the associations with mobility was small to moderate and varied depending on the difficulty of the mobility task.

This study contributes to the existing SLSS literature in two ways: (1) it evaluated mobility skills beyond walking; (2) it evaluated a broad range of neuromuscular attributes associated with longitudinal change comparing participants with and without SLSS. Findings from this study identified 3 neuromuscular attributes that can be targeted in rehabilitative care among community-dwelling older adults with and without SLSS: trunk endurance, leg strength and knee flexion ROM. This recommendation is supported by previous studies among older adults in general that demonstrate improvements in mobility when exercise targets impaired neuromuscular attributes.^{32, 38} While leg strength and knee flexion ROM have been emphasized previously within spine literature trunk endurance has not been prioritized for patients with SLSS.^{39, 40} Within our study, those with SLSS demonstrated greater trunk endurance impairment compared to those without SLSS (SLSS: 69.1 +/- 55.9 secs, no SLSS: 101.9 +/- 56.8 secs) (Table 1). Although trunk endurance was not isolated as a unique target for those with SLSS when this neuromuscular attribute is targeted among older adults in general mobility and balance improve.³² Further, trunk endurance has been suggested as a target for physical performance and low back pain among athletes and younger populations.^{41, 42}

When compared to participants without SLSS, those with SLSS demonstrated a higher BMI, a greater number of comorbidities, more severe global pain, and greater impairment in trunk endurance, leg strength, leg strength asymmetry, knee flexion and extension ROM and ankle ROM at baseline. On average both groups experienced a decline in mobility over two years of follow-up however, the magnitude of decline did not differ for participants with SLSS when compared to those without SLSS. These findings suggest that mobility decline may be impacted by other factors besides the presence of SLSS such as BMI, number of comorbidities and pain. Both factors were statistically higher for participants with SLSS compared to those without. Our models were conservative controlling for only age and gender to satisfy participant to covariate ratios. Another potential reason for the lack of between group differences for mobility may be the study's short follow-up time. Previous literature evaluating older adults with SLSS suggest that symptoms experienced by patients with SLSS may remain unchanged for 3 years.²⁷ These findings are important to consider for future prospective studies evaluating impairment-mobility relationships and when developing interventions that restore mobility for patients with and without SLSS.

Study Limitations

Our findings are consistent with a previous study that evaluated the longitudinal relationships of neuromuscular attributes with self-reported mobility among older adults, but without comparing associations based on the presence of SLSS.²¹ With the exception of leg speed the same neuromuscular attributes were associated with mobility for patients with SLSS. Our findings did not prioritize leg speed during performance of basic and advanced mobility tasks among community-dwelling older adults with or without SLSS. Further, the neuromuscular attributes associated with self-reported mobility for participants with SLSS were similar for those without SLSS. Participants without SLSS had additional statistical relationships. These findings may be attributed to a small sample size for the SLSS group limiting statistical power to detect additional meaningful relationships. These findings may also highlight that older adults, regardless of the presentation of SLSS present with similar impairments impacting mobility that can be targeted in rehabilitation.

Boston RISE is not a population-based study; therefore, findings may not generalize to all older adults with SLSS. Also, while our definition of SLSS is in accordance with a previously established imaging-detected LSS definition²² information for adjudicating imaging-detected LSS came from clinic reports for most of the participants. Varying reporting methods are a possibility that could result in misclassification of SLSS status. Further, as this was a secondary analysis, there are certain neuromuscular attributes that may have meaningful associations with mobility that were not evaluated within Boston RISE, including limitations in hip extension. Hip ROM was not measured within Boston RISE, although its importance for future work among the SLSS population should be emphasized.

Despite these limitations this study has certain strengths. It included a comprehensive assessment of neuromuscular attributes and mobility, key elements that are important to understand in rehabilitative care relevant to patients with SLSS that are not well described in the SLSS literature. Also, despite the small sample size the prevalence of SLSS in this study (13%) mirrors that of population-based estimates of SLSS prevalence (10–14%).⁶

Conclusions

This study identified 3 neuromuscular attributes associated with mobility at baseline and over two years of follow-up among community-dwelling older adults with and without SLSS: trunk endurance, leg strength; and knee flexion ROM and two additional attributes among those without SLSS: ankle ROM and leg strength asymmetry. Trunk endurance is a novel attribute not previously prioritized within the SLSS literature. The neuromuscular attributes are amenable to rehabilitative care and therefore, these findings may help guide rehabilitation interventions among community-dwelling older adults with SLSS.

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Presentation

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Conflicts of Interest Source of Funding

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List of Abbreviations:

CT	computerized tomography
EMR	electronic medical record

LLFDI	Late-life Function and Disability Instrument
PT	physical therapy
ROM	range of motion
SLSS	symptomatic lumbar spinal stenosis

References

1. Liao Y, McGee DL, Cao G, Cooper RS. Recent changes in the health status of the older U.S. population: findings from the 1984 and 1994 supplement on aging. *J Am Geriatr Soc.* 2001;49(4):443–449. [PubMed: 11347789]
2. Tomkins-Lane CC, Holz SC, Yamakawa KS, et al. Predictors of walking performance and walking capacity in people with lumbar spinal stenosis, low back pain, and asymptomatic controls. *Arch Phys Med Rehabil.* 2012;93(4):647–653. [PubMed: 22365377]
3. Iversen MD, Katz JN. Examination findings and self-reported walking capacity in patients with lumbar spinal stenosis. *Phys Ther.* 2001;81(7):1296–1306. [PubMed: 11444993]
4. Iversen MD, Kale MK, Sullivan JT Jr. Pilot case control study of postural sway and balance performance in aging adults with degenerative lumbar spinal stenosis. *J Geriatr Phys Ther.* 2009;32(1):15–21. [PubMed: 19856631]
5. Stucki G, Liang MH, Lipson SJ, Fossel AH, Katz JN. Contribution of neuromuscular impairment to physical functional status in patients with lumbar spinal stenosis. *J Rheumatol.* 1994;21(7):1338–1343. [PubMed: 7966081]
6. Ishimoto Y, Yoshimura N, Muraki S, et al. Prevalence of symptomatic lumbar spinal stenosis and its association with physical performance in a population-based cohort in Japan: the Wakayama Spine Study. *Osteoarthritis Cartilage.* 2012;20(10):1103–1108. [PubMed: 22796511]
7. Ciol MA, Deyo RA, Howell E, Kreif S. An assessment of surgery for spinal stenosis: time trends, geographic variations, complications, and reoperations. *J Am Geriatr Soc.* 1996;44(3):285–290. [PubMed: 8600197]
8. Delitto A, George SZ, Van Dillen LR, et al. Low back pain. *J Orthop Sports Phys Ther.* 2012;42(4):A1–57.
9. Peterson LE, Goodman C, Karnes EK, Chen CJ, Schwartz JA. Assessment of the quality of cost analysis literature in physical therapy. *Phys Ther.* 2009;89(8):733–755. [PubMed: 19556332]
10. World Health Organization. International Classification of Functioning, Disability and Health (ICF) Geneva: World Health Organization; 2001.
11. Fritz JM, Lurie JD, Zhao W, Whitman JM, Delitto A, Brennan GP, Weinstein JN Associations between physical therapy and long-term outcomes for individuals with lumbar spinal stenosis in the SPORT study. *Spine J.* 2014;14(8):1611–21. [PubMed: 24373681]
12. Delitto A, Piva SR, Moore CG, et al. Surgery versus nonsurgical treatment of lumbar spinal stenosis: a randomized trial. *Ann Intern Med.* 2015;162(7):465–473. [PubMed: 25844995]
13. Guide to Physical Therapist Practice 3.0.: Alexandria, VA: American Physical Therapy Association; 2014.
14. Whyte J Contributions of treatment theory and enablement theory to rehabilitation research and practice. *Arch Phys Med Rehabil.* 2014;95(1 Suppl):S17–23.e12.
15. Ammendolia C, Stuber KJ, Rok E, et al. Nonoperative treatment for lumbar spinal stenosis with neurogenic claudication. *Cochrane Database Syst Rev.* 2013;8:Cd010712.
16. Schmidt CT, Ward RE, Suri P, et al. Health Characteristics, Neuromuscular Attributes, and Mobility Among Primary Care Patients With Symptomatic Lumbar Spinal Stenosis: A Secondary Analysis. *J Geriatr Phys Ther.* 2017;40(3):135–142. [PubMed: 27007991]
17. Schmidt CT, Ward RE, Suri P, et al. Association of Neuromuscular Attributes With Performance-Based Mobility Among Community-Dwelling Older Adults With Symptomatic Lumbar Spinal Stenosis. *Arch Phys Med Rehabil.* 2017;98(7):1400–1406. [PubMed: 28377110]

18. Holt NE, Percac-Lima S, Kurlinski LA, et al. The Boston Rehabilitative Impairment Study of the Elderly: a description of methods. *Arch Phys Med Rehabil.* 2013;94(2):347–355. [PubMed: 22989700]
19. Bean JF, Latham NK, Holt N, et al. Which neuromuscular attributes are most associated with mobility among older primary care patients? *Arch Phys Med Rehabil.* 2013;94(12):2381–2388. [PubMed: 23973445]
20. Beauchamp MK, Schmidt CT, Pedersen MM, Bean JF, Jette AM. Psychometric properties of the Late-Life Function and Disability Instrument: a systematic review. *BMC Geriatr.* 2014;14:12. [PubMed: 24476510]
21. Ward RE, Beauchamp MK, Latham NK, et al. Neuromuscular Impairments Contributing to Persistently Poor and Declining Lower-Extremity Mobility Among Older Adults: New Findings Informing Geriatric Rehabilitation. *Arch Phys Med Rehabil.* 2016;97(8):1316–1322. [PubMed: 27056644]
22. Suri P, Rainville J, Kalichman L, Katz JN. Does this older adult with lower extremity pain have the clinical syndrome of lumbar spinal stenosis? *JAMA.* 2010;304(23):2628–2636. [PubMed: 21156951]
23. Jones RN, Gallo JJ. Dimensions of the Mini-Mental State Examination among community dwelling older adults. *Psychol Med.* 2000;30(3):605–618. [PubMed: 10883716]
24. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol.* 1994;49(2):M85–94.
25. Katz JN, Dalgas M, Stucki G, et al. Degenerative lumbar spinal stenosis. Diagnostic value of the history and physical examination. *Arthritis Rheum.* 1995;38(9):1236–1241. [PubMed: 7575718]
26. Drew R, Bhandari M, Kulkarni AV, Louw D, Reddy K, Dunlop B. Reliability in grading the severity of lumbar spinal stenosis. *J Spinal Disord.* 2000;13(3):253–258. [PubMed: 10872765]
27. Jarvik JG, Hollingworth W, Heagerty PJ, Haynor DR, Boyko EJ, Deyo RA. Three-year incidence of low back pain in an initially asymptomatic cohort: clinical and imaging risk factors. *Spine.* 2005;30(13):1541–1548; discussion 1549. [PubMed: 15990670]
28. Anderson DE, Bean JF, Holt NE, Keel JC, Boussein ML. Computed tomography-based muscle attenuation and electrical impedance myography as indicators of trunk muscle strength independent of muscle size in older adults. *Am J Phys Med Rehabil.* 2014;93(7):553–561. [PubMed: 24508931]
29. Sangha O, Stucki G, Liang MH, Fossel AH, Katz JN. The Self-Administered Comorbidity Questionnaire: a new method to assess comorbidity for clinical and health services research. *Arthritis Rheum.* 2003;49(2):156–163. [PubMed: 12687505]
30. Lamon-Fava S, Wilson PW, Schaefer EJ. Impact of body mass index on coronary heart disease risk factors in men and women. The Framingham Offspring Study. *Arterioscler Thromb Vasc Biol.* 1996;16(12):1509–1515. [PubMed: 8977456]
31. Cleeland CS. Measurement of pain by subjective report In: Chapman C, Loeser JD, eds. *Advances in pain research and therapy.* New York: Raven Press; 1989:391–403.
32. Suri P, Kiely DK, Leveille SG, Frontera WR, Bean JF. Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study. *Pm r.* 2009;1(10):916–924. [PubMed: 19854420]
33. Watkins MA, Riddle DL, Lamb RL, Personius WJ. Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. *Phys Ther.* 1991;71(2):90–96; discussion 96–97. [PubMed: 1989012]
34. Milne JS, Williamson J. A longitudinal study of kyphosis in older people. *Age Ageing.* 1983;12(3):225–233. [PubMed: 6624608]
35. Haley SM, Jette AM, Coster WJ, et al. Late Life Function and Disability Instrument: II. Development and evaluation of the function component. *J Gerontol A Biol Sci Med Sci.* 2002;57(4):M217–222.
36. Carpenter JR, Kenward MG, White IR. Sensitivity analysis after multiple imputation under missing at random: a weighting approach. *Stat Methods Med Res.* 2007;16(3):259–275. [PubMed: 17621471]

37. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform.* 2009;42(2):377–381. [PubMed: 18929686]
38. Bean JF, Kiely DK, LaRose S, O'Neill E, Goldstein R, Frontera WR. Increased velocity exercise specific to task training versus the National Institute on Aging's strength training program: changes in limb power and mobility. *J Gerontol A Biol Sci Med Sci.* 2009;64(9):983–991. [PubMed: 19414509]
39. Goren A, Yildiz N, Topuz O, Findikoglu G, Ardic F. Efficacy of exercise and ultrasound in patients with lumbar spinal stenosis: a prospective randomized controlled trial. *Clin Rehabil.* 2010;24(7): 623–631. [PubMed: 20530650]
40. Koc Z, Ozcakar S, Sivrioglu K, Gurbet A, Kucukoglu S. Effectiveness of physical therapy and epidural steroid injections in lumbar spinal stenosis. *Spine.* 2009;34(10):985–989. [PubMed: 19404172]
41. Dejanovic A, Harvey EP, McGill SM. Changes in torso muscle endurance profiles in children aged 7 to 14 years: reference values. *Arch Phys Med Rehabil.* 2012;93(12):2295–2301. [PubMed: 22503935]
42. Chok B, Lee R, Latimer J, Tan SB. Endurance training of the trunk extensor muscles in people with subacute low back pain. *Phys Ther.* 1999;79(11):1032–1042. [PubMed: 10534796]

Figure 1 :
Flowchart Indicating Study Inclusion

Table 1

Baseline Demographics, Health Factors, Neuromuscular Attributes and Measures of Mobility among Participants with and without SLSS

	SLSS* (n=54)	n	No SLSS* (n=246)	n	p value	95% CI
Demographics/Health Factors						
Age (years)	76.9(6.6)	54	77.1(7.2)	246	0.86	(-1.9, 2.3)
Gender (% female)	36(67%)	54	164(67%)	246	1.00	----
Education high school college	28(53%) 25(47%)	53	92(37%) 154(63%)	246	0.04	----
Comorbidities (0–13)	4.9(2.1)	54	3.6(1.7)	246	<0.001	(-1.9, -0.7)
BMI	30.9(5.7)	52	28.7(5.7)	245	0.01	(-3.9, -0.5)
Brief Pain Inventory (0–10)	4.0(1.6)	53	2.1(1.8)	246	<0.001	(-2.5, -1.4)
MMSE (0–30)	27.4(2.3)	53	27.4(2.4)	246	0.94	(-0.7, 0.7)
Neuromuscular Attributes						
Trunk Extensor Muscle Endurance (seconds)	69.1(55.9)	54	101.9(56.8)	246	<0.001	(15.2, 50.4)
Leg Strength (Newtons/kg)	8.4(2.5)	54	9.6(2.7)	246	<0.01	(0.4, 2.0)
Leg Strength Asymmetry	1.3(0.6)	54	1.2(0.2)	246	0.04	(-0.2, -0.002)
Leg Speed (meters/second)	0.97(0.31)	54	1.0(0.23)	246	0.50	(-0.06, 0.1)
Knee Flexion ROM(degrees)	120.1(18.8)	54	126.2(13.1)	246	0.01	(1.84, 10.4)
Knee Flexion ROM Difference (degrees)	7.3(10.5)	54	5.3(6.2)	246	0.19	(-5.0, 1.0)
Knee Extension ROM (degrees)	6.4 (5.5)	54	9.6(6.1)	246	<0.001	(1.4, 5.0)
Knee Extension ROM Difference (degrees)	2.9(2.4)	54	3.3(3.0)	246	0.33	(-0.4, 1.3)
Ankle ROM (% impaired)	26(49%)	54	67(27%)	246	<0.01	----
Kyphosis [†]	10.3(3.4)	54	10.6(3.1)	246	0.64	(-0.7, 1.2)

* Mean(standard deviation) or frequency(percentage),

[†]=kyphosis measure=height/length of flexicurve measure 100

Table 2

Within Group Differences for Basic and Advanced Mobility among Participants with and without SLSS

Mobility Measures	Baseline *	Year Two *	Mean Difference *	p-value	95% CI
SLSS	59.5(11.2)	56.1(11.3)	2.70 (8.68)	0.04	(0.18, 5.21)
LLFDI-Basic Mobility	33.5(14.4)	29.4(16.2)	4.11 (12.84)	0.03	(0.39, 7.84)
LLFDI-Advanced Mobility					
No SLSS	68.7(11.9)	68.1(14.6)	1.05 (12.28)	0.22	(-0.63, 2.72)
LLFDI-Basic Mobility	45.5(14.3)	43.0(16.4)	3.25 (10.38)	<0.001	(1.84, 4.67)
LLFDI-Advanced Mobility					

* Mean(standard deviation), CI=Confidence Interval, LLFDI=Late-life Function and Disability Instrument

Table 3

Association of Neuromuscular Attributes with Late-life Function and Disability among Participants with and without SLSS at Baseline

Outcome	Variables	n	Beta Coefficient	95% CI	p value
SLSS					
		R ² =0.27			
LLFDI	trunk extensor muscle	54	0.06	(0.002,0.12)	0.04
Basic Mobility	endurance (secs)				
	leg strength (N/kg)		1.85	(0.43,3.27)	0.01
		R ² =0.47			
Advanced Mobility	leg strength (N/kg)	54	2.19	(0.68,3.69)	<0.01
	knee flexion ROM (deg)		0.34	(0.17,0.52)	<0.001
No SLSS					
		R ² = 0.38			
LLFDI	trunk extensor muscle	246	0.04	(0.02,0.07)	<0.01
Basic Mobility	endurance (secs)				
	leg strength (N/kg)		1.31	(0.72,1.90)	<0.001
	ankle ROM (deg)		4.12	(1.07, 7.24)	<0.01
		R ² = 0.20			
Advanced Mobility	trunk extensor muscle	246	0.05	(0.02, 0.08)	<0.001
	endurance (secs)				
	leg strength (N/kg)		2.21	(1.57, 2.86)	<0.001
	leg strength asymmetry		-8.75	(-16.50, -1.01)	0.03
	knee flexion ROM (deg)		0.19	(0.08, 0.31)	<0.01

LLFDI: Late-life Function and Disability Instrument, secs=seconds, N/kg=Newtons/kilogram, deg=degrees.

Models were adjusted for age and gender. R²=adjusted R²

Interpretation of associations: a 1 N/kg increase in leg strength is associated with a 1.85 unit improvement in LLFDI basic mobility. A 1 degree increase in knee flexion ROM is associated with a 0.34 unit improvement in LLFDI advanced mobility.

Table 4

Association of Neuromuscular Attributes with a Change in Late-life Function and Disability Across Two Years of Follow-up Among Participants with SLSS

Outcome	Variables	N	Beta Coefficient	95% CI	p value
SLSS	trunk extensor muscle	53	0.06	(0.006,0.11)	0.03
LLFDI	endurance (secs)				
Basic Mobility	leg strength (N/kg)		1.58	(0.35,2.82)	0.01
R ² = 0.29	time: year 1		-0.68	(-2.91,1.56)	0.55
	time: year 2		-2.97	(-5.27,-0.67)	0.01
Advanced	trunk extensor muscle	53	0.09	(0.03,0.14)	<0.001
Mobility	endurance (secs)				
R ² =0.42	knee flexion ROM (deg)		0.37	(0.22,0.51)	<0.001
	time: year 1		0.04	(-3.14,3.23)	0.98
	time: year 2		-4.37	(-7.64,-1.10)	<0.01
No SLSS					
LLFDI	trunk extensor muscle	246	0.05	(0.02, 0.07)	<0.001
Basic Mobility	endurance (secs)				
R ² = 0.22	leg strength (N/kg)		1.21	(0.65,1.76)	<0.001
	knee flexion ROM (deg)		0.12	(0.02, 0.23)	0.02
	ankle ROM (deg)		3.15	(0.21, 6.09)	0.04
	time: year 1		0.58	(-2.03, 3.62)	0.42
	time: year 2		-1.06	(-2.48, 0.36)	0.14
Advanced	trunk extensor muscle	246	0.06	(0.03, 0.09)	<0.001
Mobility	endurance (secs)				
R ² = 0.36	leg strength (N/kg)		2.17	(1.56, 2.78)	<0.001
	knee flexion ROM (deg)		0.23	(0.12, 0.34)	<0.001
	time: year 1		-0.19	(-1.43,1.05)	0.76
	time: year 2		-3.16	(-4.43,-1.89)	<0.001

95% CI=95% confidence interval, LLFDI= Late-life Function and Disability Instrument, secs=seconds, N/kg=Newtons/kilogram, ROM= range of motion, deg=degrees. Models were adjusted for age and gender.