Surgical Recovery for Patients with Concomitant Hypertension and Lumbar Spinal Stenosis

by

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Abstract

Introduction: Lumbar Spinal Stenosis (LSS) is a prevalent musculoskeletal condition affecting 8-11% of the United States general population. LSS is the most common reason requiring lumbar spine surgery in adults older than 65 years, with an adjusted rate of 135.5 low back surgeries per 100,000 Medicare beneficiaries. The onset of symptoms typically begins at 50 years of age and often results in localized and radiating leg pain, which limit activities such as walking. Patients with confirmed LSS may be candidates for surgery if conservative treatments have failed to manage symptoms. Patients who received surgery for LSS compared to conservative treatment experience greater improvement in pain relief, function, patient satisfaction and self-report recovery up to 4 years after treatment. The prognostic factors of poor post-operative functional outcome included: depression, cardiovascular comorbidity, disorder influencing walking ability, and scoliosis. High blood pressure (HBP) is reported in 23.2-48.3% of patients with LSS and is associated with lower health status. It is unclear whether HBP affects LSS surgical outcomes.

Objective: The primary objective of this cohort study was to evaluate whether HBP was associated with poor recovery following LSS-related surgery. The secondary objectives are (1) to identify the rate of pre-surgical HBP in this community-based LSS cohort, (2) to determine whether the rate or type of post-surgical complications differ between participants with and without HBP, and (3) to describe functional recovery after surgery for LSS.

Methods: Patients were identified as study candidates at the time of magnetic resonance imaging in Calgary, Alberta between April 2004 and May 2005. After implementing the study inclusion and exclusion criteria, the cohort comprised 97 participants who received spinal surgery for LSS and were followed over 2 years. Disability status was assessed pre- and post-operatively using the Oswestry Disability Index (ODI), a disease-specific questionnaire. HBP was identified by self-report, anti-hypertensive medication use, and/or diagnosis of HBP prior to surgery using Alberta Health (AH) data. Participants were interviewed before surgery and within 2 years after surgery. A multiple linear regression model was used to assess HBP as a prognostic factor for post-operative disability status. Potential confounders were included in the model to control for the effect of HBP on post-operative ODI.

Results: Of the 97 participants who had back surgery, 46 were surgical participants identified by self-report alone and 25 by AH data alone, and 26 participants who were identified by both sources. The study cohort had a mean age of 71.8 (SD 12.9) years, 52% were women, and the mean number of comorbidities was 2.3 (SD 1.9). The mean ODI score was 59.0 (SD 17.0) pre-operatively and 30.1 (SD 17.7) post-operatively. Forty-nine (50.5%) participants were hypertensive. Regardless of blood pressure status, large gains in function were seen up to 2 years after surgery for LSS (effect size: 1.73; 95% CI: 1.39, 2.06). Of the 51 participants with available surgical data, 20 (39.2%) participants experienced at least one post-surgical complication, and had a median length of hospital stay of 5.0 (IQR 3.0-8.0) days.

Comparing participants with and without HBP, baseline group differences were not seen for gender, follow-up time, pre-operative ODI score, or depression. No group differences were seen post-operatively on the ODI comparing the HBP group (mean 30.1, SD 17.7) and the non-HBP group (mean 28.7, SD 17.1, p=0.699).

After controlling for age, gender, follow-up time, pre-operative ODI, number of comorbidities and depression, the post-operative ODI score was 1.32 units higher for participants with pre-existing HBP compared to those without HBP (95% CI: -5.64, 8.28, p= 0.747). The standardized coefficient revealed that a 1-point increase in pre-operative ODI score was associated with a 0.38-point increase in ODI post score (95% CI: 0.16, 0.60).

Conclusion: Although earlier work suggested that hypertensive patients with LSS have lower scores for overall health-related quality of life than those without HBP, hypertension does not appear to have a deleterious effect on functional recovery after LSS-related surgery. Consistent with the findings from other research, our study cohort experienced large gains in functional recovery and symptom reduction up to 2 years after surgery regardless of HBP. For patients whose conservative management fails to relieve symptoms and are concerned about undergoing LSS-related surgery, our findings show that participants were likely to see improvements in disability status.

"Here's to the crazy ones — the misfits, the rebels, the troublemakers, the round pegs in the square holes. The ones who see things differently — they're not fond of rules. You can quote them, disagree with them, glorify or vilify them, but the only thing you can't do is ignore them because they change things. They push the human race forward, and while some may see them as the crazy ones, we see genius, because the ones who are crazy enough to think that they can change the world, are the ones who do."

- Steve Jobs

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List of Abbreviations

AH	Alberta Health
BMI	Body Mass Index
BP	Blood Pressure
CES-D	Centre for Epidemiologic Studies Depression scale
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
CT	Computed Tomography
DM	Diabetes Mellitus
ES	Effect Size
ESI	Epidural Steroid Injection
HBP	High Blood Pressure
HRQL	Health-related Quality of Life
HUI	Health Utility Index
ICD	International Classification of Diseases
JOA	Japanese Orthopedic Association
LSS	Lumbar Spinal Stenosis
MCID	Minimal Clinically Important Difference
MLR	Multiple Linear Regression
MODEMS	Musculoskeletal Outcomes Data Evaluation and Management System
MOS	Medical Outcomes Social Support
MRI	Magnetic Resonance Image
NSAID	Nonsteroidal Anti-inflammatory Drug
ODI	Oswestry Disability Index
OQLQ	Osteoporosis Quality of Life Questionnaire
OR	Odds Ratio
SD	Standard Deviation
SE	Standard Error
SF-36	Short Form 36 Health Survey
SSS	Swiss Spinal Stenosis
VAS	Visual Analogue Scale

Chapter I: Introduction

Problem Statement

Lumbar Spinal Stenosis (LSS) is a commonly diagnosed spinal condition and is the most common reason for lumbar spine surgery in adults older than 65 years (Aalto et al., 2006). The pathophysiology of anatomical LSS is one where the available space for neural and vascular elements is diminished in the lumbar region of the spine (Kreiner et al., 2013). The specific etiology may result from the thickening of the ligamentum flavum, an intervertebral disc bulge, or a bony spur in the spinal canal (Chen & Spivak, 2003). Given the worsening of symptoms with increasing age, the condition is referred to as degenerative LSS, whereas congenital spinal stenosis is present at birth. The current study will focus on degenerative lumbar spinal stenosis.

Older age is the primary risk factor for degenerative LSS (Shamie, 2013). The onset of symptoms typically begins at age 50, and often includes, but is not limited to, pain, numbness, cramping and weakness in the back, leg or buttocks (Sirvanci et al., 2008). Although Canadian prevalence statistics for LSS have not been reported, the prevalence of LSS in the American general population is between 8 and 11% (Shamie, 2013). Current estimates indicate that 13-14% of individuals seeking treatment from a specialist for low back pain are diagnosed with LSS (Abbas et al., 2013). In 2007, there were 37,598 operations to treat LSS in the US, with an estimated aggregated hospital bill for $1.65 billion (2009 USD), which highlights the financial impact on the healthcare budget (Deyo et al., 2010).

Patients with unsuccessful conservative treatments may be candidates for surgery, a procedure that is performed either by an orthopedic surgeon or neurosurgeon. A systematic review has demonstrated that surgery is superior to nonsurgical management for controlling pain and improving function in patients with LSS (Kovacs et al., 2011). The primary goal of surgery is to reduce the patient's symptoms and to improve functional ability. Surgical recovery for this patient population may vary depending on a number of prognostic factors, such as their pre-operative symptom severity. Because of the progressive nature of LSS, patients with severe and prolonged symptoms undergo surgical treatment in their 60s and 70s (Shamie, 2013). Given Canada's aging population, the number of patients seeking treatment will likely contribute to an increase in the number of surgeries for LSS.

Recent years have seen a dramatic increase in the volume and complexity of LSS-related surgery in the United States (Kim et al., 2013). A rise in the number of surgeries for LSS has also seen a rise in success rates (Gelalis et al., 2006). Research suggests, however, that surgical recovery is increasingly compromised for patients with a greater number of comorbidities (Niggemeyer et al., 1997; Foulongue, et al. 2012; Katz et al. 1999; Battie et al., 2012). The number and type of comorbidities having the most significant impact on surgical recovery remains unknown for patients with LSS. A frequently occurring comorbidity for patients with LSS is hypertension, or sometimes referred to as high blood pressure (HBP) (Uesugi et al., 2013; Lotan et al., 2008). Other research has shown a relationship between patients with HBP and poorer surgical outcomes following shoulder,

hip, and knee arthroplasty, but it is unclear whether surgical outcomes to treat LSS are affected by HBP (Jain et al., 2005).

Because HBP has no signs or symptoms, it is often referred to as a 'silent killer' that becomes lethal in severe cases of the disease. HBP is highly prevalent in the general population (22,709 per 100,000) and is associated with other conditions such as stroke, ischemic heart disease, peripheral vascular disease and heart failure (Robitaille et al., 2012). The criterion for diagnosis of arterial HBP is a systemic blood pressure greater than 140/90 mmHg on two or more occasions (Foex & Sear, 2004). The Public Health Agency of Canada reported that every 20/10 mmHg increase in blood pressure (BP) doubles the risk of cardiovascular mortality from a cardiovascular disease (2010).

A Japanese study found that the prevalence of HBP in patients with LSS was 39.3% between the ages of 50-69 (Uesugi et al., 2013). The prevalence of HBP in the general Japanese population is 23.0%, the same prevalence as in Canada. Moreover, uncontrolled HBP has been shown to negatively affect the health-related quality of life (HRQL) of individuals in the general population (Carvalho et al., 2013). Based on current literature, hypertensive patients have been shown to have a decreased HRQL on the Short Form 36 Health Survey (SF-36), and with the addition of at least one other concomitant chronic condition, HRQL is further lowered (Carvalho et al., 2013). For example, patients with degenerative diseases such as osteoarthritis combined with uncontrolled HBP have a lower HRQL compared to those with osteoarthritis alone (Carvalho et al., 2013). Given this

information, further research is necessary to investigate the effects of HBP in patients with LSS on their surgical recovery.

Objectives

The overall aim of this prospective cohort study is to examine the relationship of HBP in patients aged 40 years or older and the recovery after surgical treatment for LSS. The primary objective is to determine whether HBP is a prognostic factor of functional recovery after LSS-related surgery.

The secondary objectives are to:

1) Identify the rate of pre-surgical HBP in this community-based LSS cohort.
2) Determine whether the rate or type of post-surgical complications differ between participants with and without HBP.
3) Determine the overall functional recovery after surgery for LSS.

Hypothesis

At 6 months follow-up, LSS patients with HBP will experience worse surgical outcomes than those without HBP.

Significance of Findings

LSS is a degenerative disease that remains not only an economic burden, but also a burden for patients suffering from the disease. The increasing prevalence of LSS and associated health care costs demand a better understanding of this condition, including

improved treatment outcomes. Further research is warranted to improve health outcomes for patients undergoing surgical interventions.

Results from this research will support or fail to support the assertion that recovery is impaired for patients with HBP who receive surgical treatment for LSS. This study will assess HBP as a prognostic factor of surgical outcome for LSS to inform clinicians of patients who may require further monitoring after surgery. Clinicians may also use this research to provide better-informed consultations and to manage expectations for patients with LSS. Furthermore, the findings will provide new insight into the prevalence and associations of HBP with LSS in a Canadian context.

Chapter II: Literature Review

The purpose of this literature review is to provide an introduction to the over-arching topics presented in this thesis. The supporting literature is intended to give further understanding of various aspects of this study including: anatomy of the spine; clinical symptoms and diagnosis of lumbar spinal stenosis (LSS); surgical and non-surgical treatment of LSS; complications and prognostic factors of surgical recovery; a review of HRQL questionnaires and, lastly, arterial HBP. Information from the literature review will provide a foundation for an informed discussion that will address the objectives of this study.

Spinal Anatomy

It is important to understand spinal canal anatomy to grasp the pathophysiology of degenerative LSS (see Fig. 1). The posterior arches of the vertebrae, known as the laminae, and the ligamentum flavum form the posterior border of the vertebral canal (Chen & Spivak, 2003). The anterior border of the vertebral canal consists of the posterior edge of the vertebral bodies and intervertebral disks (Chen & Spivak, 2003). Pedicles make up the lateral borders of the vertebral canal, which attach the posterior arches to the vertebrae anteriorly (Chen & Spivak, 2003). The spinal cord extends from the caudal end of the medulla oblongata in the brain, exiting the cranial vault through the foramen magnum and into the spinal canal (Goshgarian, 2003). At the caudal end, the spinal cord tapers at the level of the intervertebral disk between L1 and L2 (Goshgarian, 2003). The spinal nerves exit segmentally through the spaces between the pedicles, called the neural foramina

(Goshgarian, 2003). Positioned posterolaterally at the level of the disk space are the facet joints, which are located bilaterally along the vertebrae (Chen & Spivak, 2003).

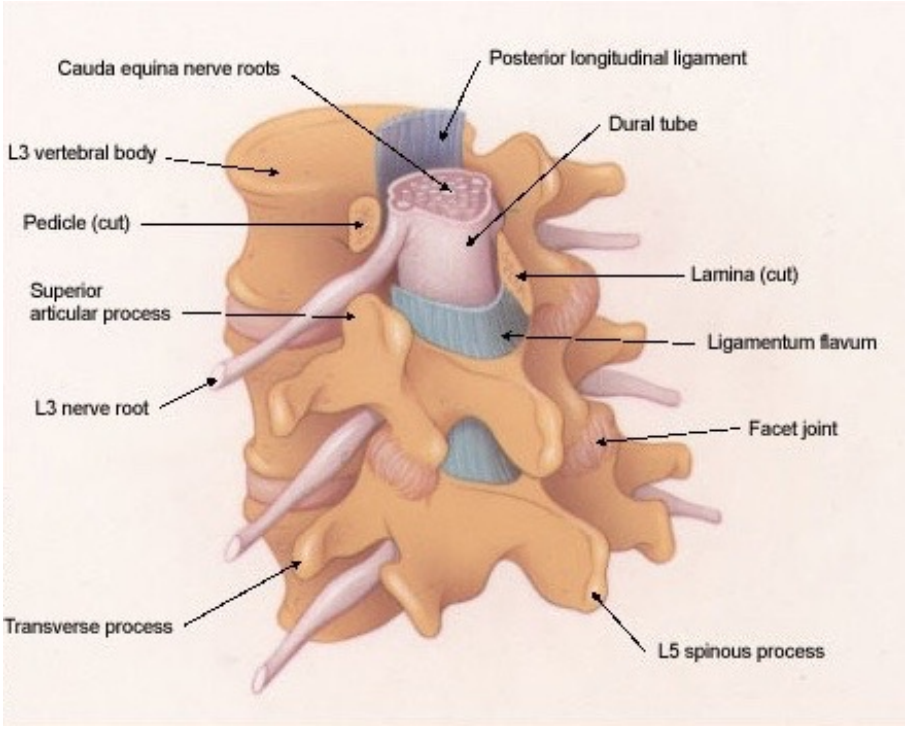

Figure 1 Anatomy of Lumbar Vertebra (L5). Adapted from "Lumbar spine stenosis: A common cause of back and leg pain" by J.A. Alvarez and R.H. Hardy, 1998, *American Family Physician, 57,* p.1826. Copyright 1998 Marcia Hartsock.

Lumbar spinal stenosis results from mechanical factors and/or biochemical alterations within the intervertebral disk that may lead to disk space collapse, facet joint hypertrophy, soft-tissue infolding and osteophyte formation (Sirvanci et al., 2008). This leads to a narrowing of the space available for the thecal sac of the dura mater and exiting nerve roots (Sirvanci et al., 2008). Degenerative changes may constrict the lumbar canal, lateral recesses and/or neural foramina (Chen & Spivak, 2003). The lateral recess is the space within the vertebral canal that is adjacent to the location where the nerve roots exit. As a result of constriction, nerves exiting the lumbar region are impinged and may become

irritated, in this case due to disc herniation as seen in *Figure 2*. Interestingly, the degree of nerve compression on computed tomography (CT) or magnetic resonance image (MRI) is not associated with symptom severity in the LSS patient population, and in some cases, spinal stenosis is asymptomatic (Kreiner et al., 2013; Mofidi et al., 2002; Postacchini, 1999).

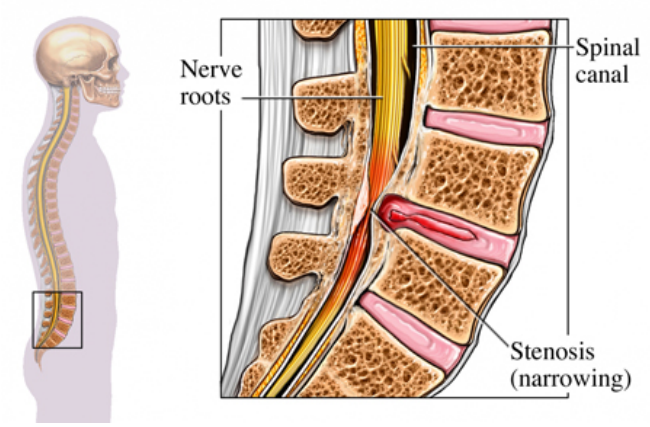

Figure 2 Central Canal Nerve Impingement. Brain and Spine Surgery. Retrieved June 12, 2013 from http://sehati.org/index/patientresources/neurosurgicalprocedures/xstopplacement.html. Copyright 2010 Nucleus Medical Media.

Central canal stenosis may cause impingement when there is degenerative enlargement of the facet joints (Chen & Spivak, 2003). When stenosis occurs more laterally, this is called lateral recess stenosis, a case where the nerve root moves toward the foramen (Chen & Spivak, 2003). When there is narrowing of the neural foramen, this is referred to as foraminal stenosis, which may compress the exiting nerve root (Chen & Spivak, 2003), seen below:

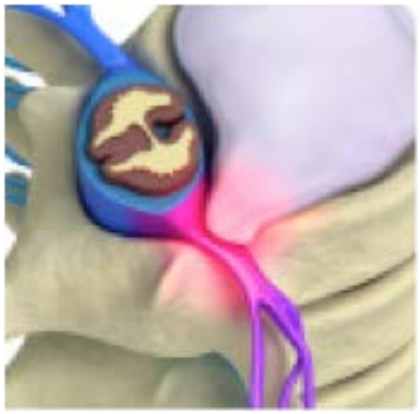

Figure 3 Foraminal Nerve Impingement. Adapted from Deuk Spine Institute, Nerve Root Impingement. Retrieved June 12, 2013 from http://www.deukspine.com/nerve-root-impingement/causes. Copyright 2012 Deuk Spine Institute.

Congenital LSS may occur from narrow spinal dimensions throughout a person's early development or bone dysplasias, such as dwarfism (Chen & Spivak, 2003). Congenital LSS is an example of anatomical LSS whereby there is diminished space available for neural and vascular elements that is not degenerative in nature (Chen & Spivak, 2003). Risk factors for congenital LSS may stem from less common non-degenerative disorders (Table 1.1) that should be eliminated from the differential diagnosis for patients not showing radiographic evidence of degenerative changes (Chen & Spivak, 2003).

Table 1.1 Non-degenerative conditions that may contribute to lumbar spinal stenosis
Bone dysplasia
Calcium pyrophosphate deposition
Congenitally short pedicles (e.g. achondroplastic dwarfism)
Diffuse idiopathic skeletal hyperostosis
Metabolic bone disease (e.g. hypoparathyroidism, renal osteodystrophy)
Ossification of the posterior longitudinal ligament
Paget's disease of bone
Previous lumbar surgery
Senile ankylosing hyperostosis of the spine
Tumors (e.g. epidural lipoma, intraspinal tumors or cysts)
Vertebral osteomyelitis (e.g. disk-space infection)

Clinical Presentation

Symptomatic LSS clinically manifests as varying degrees of pain, cramping, numbness and/or weakness in the buttocks, leg and lower back (Sirvanci et al., 2008). In severe cases, symptoms may include bowel or bladder disturbances (Alvarez & Hardy, 1998). Other research has found insufficient evidence supporting that spinal canal narrowing seen on MRI or CT scans is correlated with the severity of symptoms or level of physical dysfunction (Kreiner et al., 2013). LSS symptoms may progress with prolonged standing, activity, or positions involving lumbar extension (Chen & Spivak, 2003). Symptoms are relieved by sitting, recumbent positions, or other positions that decrease the level of lumbar lordosis, such as forward bending (Chen & Spivak, 2003). Consequently, many patients adopt a standing position with knees and hips slightly flexed resembling a 'simian stance' (Genevay & Atlas, 2010). Most non-specific low back pain worsens with prolonged sitting, but for patients with LSS, pain is relieved after sitting (Genevay & Atlas, 2010). Patients often report a reduction in standing time or distances walked before symptom onset is reported (Chen & Spivak, 2003).

Symptoms related to pain, numbness and cramping of the lower extremities are referred to as neurogenic intermittent claudication and are typical in this patient population (Alvarez & Hardy, 1998). Compared to lying supine, patients report less neurogenic claudication symptom relief when lying on the side in a position of lumbar flexion, which is subjectively more comfortable (Genevay & Atlas, 2010). Clinical guidelines reported by Kreiner et al. indicated that there is insufficient evidence for the diagnostic reliability of patient-reported dominance of lower extremity pain and low back pain (2013). Neurogenic

intermittent claudication must be distinguished from vaso-occulusive claudication caused by atherosclerosis of the pelvofemoral arteries. In contrast to patients with neurogenic intermittent claudication, those with vaso-occulusive claudication do not obtain relief with changes in posture (Alvarez & Hardy, 1998). Instead, patients with vaso-occulusive claudication experience relief with rest after ambulation even while in the upright position (Alvarez & Hardy, 1998).

Diagnosis

Diagnosis of LSS is based upon a clinical history of the patient, followed by a physical examination if clinical symptoms of LSS are present (Alvarez & Hardy, 1998). Radiological instruments such as CT and MRI confirm the diagnosis of LSS by measuring the diameter of the central canal, neural foramen, or lateral recess (Alvarez & Hardy, 1998). Clinical guidelines for the diagnosis and treatment of LSS suggest that MRI is the more appropriate and non-invasive test to confirm lumbar stenosis or nerve impingement (Kreiner et al., 2013). Currently, there are no established criteria for the diagnosis of LSS. Many researchers and physicians use a combination of clinical signs, symptoms and radiological findings (Steurer et al., 2011). There is insufficient evidence for or against consistent physical findings for the diagnosis of degenerative LSS, including sensorimotor deficits, across all patients (Kreiner et al., 2013). There is also insufficient evidence for the use of self-report questionnaires to improve the accuracy of diagnosing LSS (Kreiner et al., 2013). Research has described the need for consensus on unambiguous radiological criteria to define LSS for the improvement of diagnostic accuracy (Steurer et al., 2011).

Diagnosis of LSS is confirmed most commonly at the level of L3 to L5; however, spinal stenosis may occur at any level in the lumbar region (Alvarez & Hardy, 1998). A systematic review showed that diagnosis criteria most often applied for central stenosis was taken via MRI measurement of the antero-posterior diameter and the cross-sectional area of the vertebral canal (Steurer et al., 2011). For lateral stenosis, measurement of the height and length of the recess and the foraminal diameter for foraminal stenosis is the criterion most often applied to establish diagnosis (Steurer et al., 2011). For patients whom MRI testing is either contraindicated or inconclusive, CT myelography followed by a CT scan is the preferred test to confirm the presence of anatomical narrowing of the spinal canal or the presence of nerve impingement (Kreiner et al., 2013).

A challenge with determining the extent of LSS pathology on magnetic resonance images is the limited research on the quantitative measurement of changes seen on the image scan. Signal intensity changes occurring on vertebral endplates and subchondral bone seen on magnetic resonance images are referred to as Modic changes (Zhang et al., 2008). Modic changes are a common phenomenon for patients with degenerative conditions such as LSS, and are strongly associated with low back pain (Zhang et al., 2008). To address this challenge, Y. Wang et al. developed quantitative measures to assess the severity of Modic changes that provide precise and reliable measurements for further clinical research (2011).

Natural History

The natural history of LSS is variable but has not been shown to worsen rapidly over time (Steurer et al., 2011). In most cases, LSS is a relatively stable condition, with severe disability and neurological impairments usually developing gradually (Steurer et al., 2011). Because age (>50 years) is a major risk factor for degenerative LSS, the symptomology of the condition negatively affects HRQL in the elderly (Saban et al., 2007). Patients receiving 1 or 2 level decompressive surgery for LSS are likely to experience an improvement in HRQL comparable to the surgical success of those who have undergone knee replacement for osteoarthritis (Genevay & Atlas, 2010).

Gender Differences

Current research has not described the diagnosis of LSS as affecting one specific gender over another (Ishimoto et al., 2012). There is limited evidence to support that a greater number of males are diagnosed with LSS compared to females, although, male gender is associated with better post-operative walking ability (Aalto et al., 2006). One descriptive study showed that males and females with an increased body mass index (BMI) were more frequently diagnosed with LSS compared to the control group of a similar age (Abbas et al., 2013). The same study by Abbas et al. also assessed the occupations associated with a higher prevalence of LSS by gender from the following occupations: heavy manual labour; housekeeping; work requiring prolonged sitting and other. The findings suggest that males whose occupation involved heavy manual labour had a prevalence of LSS (71.3%) two times greater compared to the male control group (31.1%) (Abbas et al., 2013). Similarly,

females engaged in housekeeping activities were diagnosed with LSS (67.1%) two times greater than the female control group (30.0%) (Abbas et al., 2013).

Other gender-related findings have been reported in Japan where the overall symptomatic LSS prevalence is 9.3% (95% confidence interval (CI): 7.7, 11.3%) within the general population (Ishimoto et al., 2012). This cross-sectional study assessed 1009 participants in Japan with an average age of 66.3 years. Ishimoto et al. also reported a prevalence of symptomatic LSS of 10.1% (95% CI: 7.4, 13.8%) for men and 8.9% (95% CI: 7.0, 11.3%) for women; however, the gender difference in prevalence was not statistically significant (p=0.52) (2012). The gender-based LSS diagnosis rates by Abbas et al. (2013) and Ishimoto et al. (2012) are likely underestimated due to the long onset of symptoms requiring radiological instruments to confirm diagnosis.

Treatment

The primary goals of treatment for patients with LSS are to reduce symptoms, increase mobility and to improve HRQL. Treatment can be either conservative or surgical, depending on the severity and duration of the symptoms. For patients experiencing less severe symptoms, nonsurgical treatment consists of conservative management (home exercise, weight loss), nonsteroidal anti-inflammatory drugs (NSAIDS), physical therapy, and epidural steroid injections (ESIs) (Kreiner et al., 2013). Mild analgesics such as acetaminophen and NSAIDS are commonly prescribed oral medications, along with short course oral steroids for radicular symptoms (Chen & Spivak, 2003). Clinical guidelines for the diagnosis and treatment of LSS show insufficient evidence for or against the use of

medications to treat LSS (Kreiner et al., 2013). Physical therapy treatment focuses on therapeutic stretching of the lumbosacral spine, low back and abdominal strengthening, and general aerobic conditioning (Chen & Spivak, 2003). Current research is inconclusive for prescribing physical therapy or exercise as the sole treatment for LSS (Kreiner et al., 2013). Use of ESIs remain controversial for treating symptoms associated with LSS (Chen & Spivak, 2003). A recent study found that patients who received ESIs showed significantly less improvement on the Physical Function Scale of the SF-36 at 4-year follow up, longer surgical duration, and longer hospital stay compared to those who did not receive ESIs (Radcliff et al., 2013). Chen and Spivak report that prescription of ESIs serves as an appropriate treatment during periods of an acute flare with radicular symptoms (2003). Kreiner et al. has reported that ESIs provide symptom relief in patients with neurogenic claudication or radiculopathy for 0.5-6 months (2013).

For patients with mild to moderate symptoms, conservative treatment is an effective method to maintain quality of life (Johnsson et al., 1992). In a small clinical study that assessed 32 patients who underwent any type of conservative treatment for LSS, 4-year follow up results indicated that 70% of cases had unchanged symptoms, 15% showed improvement and 15% worsened (Johnsson et al., 1992). For patients whose symptoms of LSS do not impair HRQL or physical function, conservative treatment may be a reasonable option (Johnsson et al., 1992).

When conservative management fails to relieve symptoms or in the event of acute focal neurological deterioration or the development of acute cauda equine syndrome, patients

should be considered for surgical intervention (Chen & Spivak, 2003). A recent study compared conservative management to operative treatment using a randomized control trial (RCT). The findings suggested a greater improvement in pain relief, function, satisfaction and self-report recovery over 4 years comparing patients who received surgery to those who received non-operative care (Weinstein et al., 2010). Current literature has not evaluated whether conservative management improves the outcome for spinal stenosis compared to the natural history of the disease (Kreiner et al. 2013).

The primary goal of surgical treatment for LSS is to decompress impinged neural elements throughout the entire vertebral canal to their exit through the neural foramina (Chen & Spivak, 2003). The secondary goal is to maintain spinal stability or correct pre-operative instability of the affected vertebrae (Chen & Spivak, 2003). Surgical intervention for LSS is considered an elective surgery and is offered when conservative management has failed to improve the patient's symptoms or level of physical function (Chen & Spivak, 2003). If conservative management is unsuccessful and neurologic impediments worsen, surgery is recommended. The most common surgeries to treat the symptoms of LSS are decompressive laminectomy and lumbar fusion.

Decompressive Laminectomy

Decompressive laminectomy is the surgical procedure typically given to patients and is offered with or without spinal fusion depending on the potential for vertebral instability (Chen & Spivak, 2003). The standard surgical procedure for spinal decompression is called laminectomy, which involves removal of the spinous processes and central part of the

laminae overlying the compressed nerves (Chen & Spivak, 2003). In addition, arthritic facet joints that have become hypertrophic are shaved to alleviate compression along the neural foramen, central spinal canal or lateral recess as necessary (Chen & Spivak, 2003). Clinical guidelines for the treatment and diagnosis of degenerative LSS suggest that decompressive surgery improves outcomes in patients with moderate to severe symptoms (Kreiner et al., 2013). A primary research article assessed self-reported outcomes of decompressive laminectomy for LSS treatment in 119 patients with a mean follow-up period of 4.6 years (Tuite et al., 1994). Thirty-seven percent of patients rated their condition as 'much improved,' while 29% rated their condition as 'somewhat improved,' and the remaining 44% of patients felt their surgical outcome was unchanged or made worse (Tuite et al., 1994). Surgical treatment for LSS provides long-term (4+ years) improvement of outcomes in a large percentage of patients (Kreiner et al., 2013). Current studies on the long-term safety and effectiveness of other surgeries have yet to be established (Genevay & Atlas, 2010).

Spinal Fusion

For patients that have multilevel symptomatic LSS, some physicians have recommended decompressive laminectomy with spinal fusion as a measure of precaution for potential spinal instability (Genevay & Atlas, 2010). Spinal fusion surgery involves permanently conjoining two or more vertebrae using a bone graft or screws and rods to secure the fusion process (Chen & Spivak, 2003). Fusion is intended to reduce the risks associated with decompressive laminectomy including vertebral instability and the development of spondylolisthesis (Chen & Spivak, 2003). Spondylolisthesis refers to a condition where a

vertebra has shifted from its original alignment in the spine, which may cause impingement on the spinal nerves and is commonly seen in patients with LSS (Chen & Spivak, 2003). It remains uncertain whether spinal fusion following decompressive laminectomy is beneficial for treatment of LSS compared to decompression alone (Chen & Spivak, 2003). For many patients undergoing surgery, decompressive laminectomy may occur with or without fusion, and fusion may involve 2 or more vertebrae. A cohort study examined the effects of fusion after decompressive laminectomy on 5390 patients treated for LSS from the Swedish Spine Registry (Forsth et al., 2013). Using multivariable analysis at 2 years follow-up, the findings suggest no difference in satisfaction for patients who received decompression with fusion surgery compared to decompression alone (Forsth et al., 2013). The proportion of patients requiring subsequent LSS surgery was similar for both groups (Forsth et al., 2013).

Surgical Complications

Few large studies have assessed the complications associated with surgery for LSS; however, as with many surgeries, inherent risks exist with intervention. Consideration must be given when balancing the success and possible dangers of surgery. Post-operative spondylolisthesis is a possible complication of lumbar decompressive laminectomy if fusion is not performed on the affected segments (Chen & Spivak, 2003). Patients are at increased risk of spinal instability if a facetecomy is performed or if there is preexisting degenerative spondylolisthesis (Chen & Spivak, 2003). Serious surgical complications and deaths were rare in a study assessing surgical versus non-surgical outcomes for 654 patients treated for LSS (Weinstein et al., 2010). Nine percent of patients experienced

intraoperative complications such as a dural tear or spinal fluid leak (Weinstein et al., 2010). Intraoperatively, patients suffered a mean blood loss of 314ml and 10% required transfusions, whereas 5% of patients required transfusions post-operatively (Weinstein et al., 2010). At two years follow-up, 1.5% of patients in the surgical group died but these deaths were not treatment-related (Weinstein et al., 2010).

In another study, Deyo et al. examined different complexities of spinal stenosis procedures for 32,152 patients and measured their rate of complications following surgery (2010). Medicare claims between 2002-2007 were analyzed to assess surgical complications (Deyo et al., 2010). Decompression was given a surgical complexity score of 1, simple fusion (1-2 disk levels) was given a score of 2, and complex fusion (2 or more disk levels) was given a score of 3 (Deyo et al., 2010). The findings suggest that with increased surgical complexity there was an increase in life-threatening complications (Deyo et al., 2010). After adjustment for age, comorbidity, previous spine surgery and other features, the odds ratio (OR) of life-threatening complications for complex fusion procedures compared to decompression surgery alone was 2.95 (95% CI: 2.50, 3.49) (Deyo et al., 2010). Risk of significant medical complications and mortality increased with increasing comorbidity. Overall, 3.1% of patients who received treatment obtained major medical complications and 1.2% had wound complications. The 30-day mortality rate was 0.4% and the rates were not statistically different between men and women (Deyo et al., 2010). Results also showed that major medical complications and mortality increased for non-whites and for older-aged patients (Deyo et al., 2010). Furthermore, Deyo et al. found a 15-

fold increase in complex fusion procedures between 2002-2007, which may indicate an increasing risk for LSS surgery in the years following the assessment period (2010).

With an increase in prevalence, complexity and risk of LSS surgery, Kim et al. evaluated the longitudinal reoperation rate in a retrospective cohort study using American national health insurance data (2013). Any type of secondary lumbar surgery served as the primary endpoint for the 11,027 patients enrolled in the study (Kim et al., 2013). The adjusted reoperation rates also compared decompression only and fusion surgery to determine if increased procedural complexity affected the outcome (Kim et al., 2013). Kim et al. found the cumulative reoperation rate to be 7.2% at 1 year, 11.2% at 3 years, 14.2% at 5 years, and estimated the rate to be 22.9% at 10 years (2013). In contrast, a previous study found that the 10-year reoperation rate for LSS was 17%; however, only 10% of those were fusion procedures compared to 20% in 2003 (Hu et al., 1997). After adjusting for confounding factors, Kim et al. found no difference in reoperation rates between decompression alone and fusion surgeries ($p=0.82$) (2013). The findings by Kim et al. might suggest that increasing the number of fusion surgeries may lead to increasing rates of reoperation (2013).

A systematic review compared the effectiveness of surgery compared to non-operative treatment for LSS on pain, disability, and loss of HRQL (Kovacs et al., 2011). Of the articles included in the review, the average age of patients ranged between 62 and 70 years. The review included 5 'high quality' RCTs with a total of 918 patients, with follow-up times ranging between 2-10 years (Kovacs et al., 2011). Four of the 5 included articles involved

patients who underwent decompressive laminectomy with or without fusion, and the other article involved surgical implantation of an interspinous device (Kovacs et al., 2011). Conservative treatments included: orthosis, rehabilitation, physical therapy, exercise, hot and cold, transcutaneous electrical nerve stimulation, analgesics, NSAIDS, ultrasound and epidural steroids (Kovacs et al., 2011). In all 5 studies, surgery was associated with better results for pain relief, function, and HRQL; however, surgical treatment was not shown to improve walking distance (Kovacs et al., 2011). Kovacs et al. concluded that surgery is more effective for up to 2-4 years than non-operative treatment when the latter is unsuccessful for 3 to 6 months (2011).

Predictive Factors for Lumbar Spinal Stenosis Surgery

A predictive factor is defined as a clinical or biologic characteristic that is objectively measurable and provides information on the likely benefit from treatment or the increase in a person's risk of developing a condition or disease (Italiano, 2011). On average, patients undergoing surgical intervention for LSS will have improvements in symptom relief (Kovacs et al., 2011). Prognostic factors for functional and pain relief of surgery have been well documented in LSS research.

Currently, there is one systematic review that assesses prognostic factors leading to better post-operative functional ability and pain relief outcomes after LSS surgery (Aalto et al., 2006). A total of 21 articles were included using prospective studies as part of the selection criteria for analysis (Aalto et al., 2006). Results from the systematic review revealed that prognostic factors of poor surgical outcome such as function included:

depression, cardiovascular comorbidity, disorder influencing walking ability, and scoliosis (Aalto et al., 2006). Prognostic factors of functional outcomes after surgery for LSS included: better walking ability and self-rated health, higher income, less overall comorbidity, and pronounced central stenosis (Aalto et al., 2006). Neither age nor gender were associated with surgical outcome in 11 of the 21 included studies (Aalto et al., 2006).

A more recent article found multiple prognostic factors that affected surgical outcome in LSS surgery (Sigmundsson et al., 2012). One-hundred nine patients from the Swedish Spine Registry who underwent spinal decompression without fusion were assessed prospectively 1 year after treatment using the Oswestry Disability Index (ODI). The ODI is a disease specific, self-report health questionnaire that quantifies disability for low back pain. Leg pain exceeding 2 years predicted worse post-operative outcomes for leg and back pain, function and HRQL (Sigmundsson et al., 2012). Patients who reported regular use of analgesics pre-operatively had a 21 (95% CI: 3, 38, p=0.02) point mean increase on the Visual Analogue Scale (VAS) at 1 year follow-up compared to those not taking analgesics pre-operatively (Sigmundsson et al., 2012). Poor pre-operative physical function on the SF-36 was associated with poor post-operative function and dissatisfaction at 1 year follow-up.

More recent evidence has reported other pre-operative prognostic factors of surgical recovery. L. Ng et al. found that 100 patients with symptom duration of less than 33 months had better functional outcomes after decompression surgery for LSS (2007). The number of vertebral levels of decompression did not affect the surgical outcome (L. Ng et al., 2007).

Other recent findings suggest that for every 1 unit increase of BMI (> 30Kg/m^2) resulted in an increase of 0.26 on the Roland-Morris Disability Questionnaire (p=0.03), a health status measure for low back pain (Athiviraham et al., 2011). Results from a related study with 2633 patients indicated that obesity (BMI ≥ 30Kg/m^2) was associated with poorer outcomes and a higher degree of dissatisfaction after surgical treatment for LSS (Knutsson et al., 2013).

Evidence has suggested that residual post-operative symptoms are persistent at 2-years follow-up in patients treated for LSS, particularly for those showing more severe pre-operative symptoms (Hara et al., 2010). In a cohort study of 109 patients, 14.6% (n=13) and 30.3% (n=27) showed gait disturbance and residual leg pain/numbness, respectively (Hara et al., 2010). After adjusting for age and gender, the odds of residual leg pain/numbness were 85.6 times greater for patients with pre-operative resting numbness compared to those without pre-operative numbness symptoms (95% CI: 15.9, 1603.1, p=0.03) (Hara et al., 2010). Additionally, the odds of residual gait disturbance were 4.5 times greater for patients with pre-operative resting numbness compared to those without pre-operative numbness symptoms (95% CI: 1.2, 23.2, p=0.02) (Hara et al., 2010). Results also indicated that the odds of residual gait disturbance were 11.6 times greater for patients with pre-operative foot drop compared to those without pre-operative foot drop (95% CI: 2.5, 59.1, p<0.001) (Hara et al., 2010).

Surgeon Volume

Current literature suggests that high surgeon volume is associated with 38% lower risk of in-hospital complications, although it is unclear whether pain and functional outcomes are improved. Based on 48,971 hospital admissions from the Nationwide Inpatient Sample in the United States, hospitals with higher surgeon volume had a 38% lower odds (OR 0.62, 95%CI: 0.34, 1.13, p=0.12) for in-hospital mortality from LSS surgery compared to hospitals with lower surgeon volume (Dasenbrock et al., 2012). Stratification by surgeon volume provides a more clear representation of the complication risks associated with LSS surgery. Higher surgeon volume (>81 LSS surgeries per year) had a 27.0% protective effect for post-operative complications (OR=0.73, 95% CI: 0.62, 0.84, $p < 0.001$) compared to very-low-volume surgeons (<15 LSS surgeries per year) (Dasenbrock et al., 2012). The odds of developing a post-operative complication from very-low-volume surgeons was 1.38 as compared to a high volume surgeon (48-81 LSS surgeries per year) (95% CI: 1.19, 1.60, p=0.001) (Dasenbrock et al., 2012). In contrast, another study found no association between the experience of the surgeon and risk of post-operative complication (Imagama et al., 2011). Of the 1012 lumbar surgeries, junior surgeons with less than 10 years experience performed 440 (43.5%) and senior surgeons with 10 or more year experience performed 572 (56.5%) (Imagama et al., 2011). Intraoperative complications did not differ between junior surgeons (n=6, 1.4%) and senior surgeons (n=18, 3.1%) (Imagama et al., 2011). It was speculated, however, that experienced surgeons perform more complex surgeries increasing the risk of adverse post-operative events (Imagama et al., 2011).

Disease-Specific Measures

There have been a number of health measures used with LSS to evaluate the outcome of non-surgical and surgical treatments. Self-report has been shown to be a reliable method to identify a particular condition or illness (Kriegsman et al., 1996). The primary clinical concern of LSS is pain and activity limitation. Many measures for LSS have focused on physical functioning.

Condition-specific measures are useful for a particular type of disease/condition, or may be specific to an age group. They are generally designed for clinical applications and responsive to clinically important changes in health. Specific instruments have the benefit of being sensitive to change after an intervention, which is useful for determining the effectiveness of a treatment. A drawback of using specific instruments is that health status scores cannot be used to compare against the general population. Rather, the scores must be compared against the respondents with the same demographics and disease state. Another disadvantage is that the health status scores cannot be used to assess treatment effectiveness across different diseases. Lastly, the restricted nature of a specific instrument is such that the side effects of treatment may be not detected.

Oswestry Disability Index (ODI)

The ODI is a disease specific, self-reported questionnaire typically used in a clinical setting indicating the extent of back or leg pain restricting functional ability (McDowell, 2006, p. 498). The ODI evaluates disturbance to activities of daily life attributable to low back pain, quantifies subjective problems of patients, and reports the level of their

disability (McDowell, 2006, p. 498). The ODI consists of 10 items, using a 6-point Likert scale ranging from 0 to 5. A single summary score is generated by dividing the point total of all 10 items by 50 and multiplying by 100, resulting in a 'percent disability.' Scores between 0-20% indicate minimal disability, 20-40% moderate disability, 40-60% severe disability and scores above 60% represent the patient is severely disabled by pain in several areas of life (McDowell, 2006, p.500). In 2012, Cleland et al. analyzed the psychometric properties of 55 patients diagnosed with LSS (mean age 69.5; standard deviation (SD) 7.9 years; 43.1% females). Results indicated that the ODI had excellent test-retest reliability for patients with LSS (Intraclass correlation coefficient (ICC) = 0.86) (Cleland et al., 2012). Using Cohen's scale for effect size (ES), the ODI scored 'moderate' for internal responsiveness (Guyatt's Responsiveness Index = 0.702), whereas the external responsiveness was reported as 0.84 (Cleland et al., 2012). Construct validity was confirmed by significant interactions ($p<0.05$), comparing initial and follow-up scores at 6 weeks between a group of study participants with improved disability and one with stable disability (Cleland et al., 2012).

The minimal clinically important difference (MCID) is defined as the smallest score difference on an instrument that a patient perceives as beneficial, and is specific to the instrument used and the patient's condition (Copay et al., 2008). The MCID for the ODI was reported as 12.8 percentage points of the total score in surgical patients with LSS (Copay et al., 2008).

An advantage is that the ODI can determine a patient's functional disability in a quick, easy to comprehend questionnaire at a low cost (Fairbank et al., 2000). The authors of the ODI have created a modified version (version 2.0) that allows for the omission of the section on sex life. The modified version of the ODI does not alter the psychometric properties of the questionnaire (Vianin, 2008). If a respondent chooses not to answer the section on sex life, the point total of the other 9 sections is divided by 45 and multiplied by 100 to generate the summary score. For each section that is unanswered, the denominator is reduced by 5 points when calculating the summary score.

Swiss Spinal Stenosis (SSS) Questionnaire

The SSS questionnaire is a condition-specific measure commonly used to assess treatment outcomes for patients with LSS such as specific neuroischemic characteristics and adverse effects of walking capacity (Stucki et al., 1996). The SSS was developed by Stucki et al. and may also be referred to as either the 'Zurich Claudication Questionnaire' or the 'Brigham Spinal Stenosis Questionnaire' (1996). The self-reported tool includes two subscales, the symptom severity and physical function scale, as well as a third scale to assess patient satisfaction with treatment (Stucki et al., 1996). The symptom severity and physical function scale are to be completed by all respondents. The third scale is completed by patients who have undergone treatment for LSS; however, the Alberta LSS Study did not administer the third scale to the participants. The symptom severity scale consists of 6 items on a 5-point Likert scale, and a 7th item on a 3-point Likert scale. The responses with higher scores reflect greater symptom severity. The physical function scale includes 5 items using a 4-point Likert scale for each response, with higher scores representing more

limited physical function. A mean score is calculated within each scale. The change is calculated as the baseline score minus the follow-up score and can be expressed as either the absolute difference or as a percentage. If not more than two responses are missing in each scale, an imputed mean is calculated.

The SSS has been validated using traditional methods, supporting its validity, reliability and responsiveness to clinical change in surgical and non-surgical LSS populations (Fairbank, 2000). Using the ICC, the test-retest reliability was reported as 0.92 in surgical LSS patients (Fairbank, 2008). The internal consistency was measured using Cronbach's alpha and was reported as 0.91 for patients with LSS (Pratt et al., 2002). Psychometric properties of the SSS have not demonstrated ceiling or floor effects as a limitation of the measure (Stucki et al., 1996).

Using the Rasch model to test psychometric properties, Comer et al. suggested the SSS might require an updated version that includes three separate scales categorized as: functional disability, pain symptoms, and neuroischemic symptoms (2011). Comer et al. found two items from a scale that related to specific neuroischemic symptoms in the lower leg, which are important features for patients with LSS (2011). Such features are not captured in the generic outcome measures and would add value to the SSS (Comer et al., 2011). Comer et al. considered splitting the SSS scale but explained it would leave too few items in the original scale and adequate testing of performance would no longer be feasible (2011). The results of the SSS and the generic instruments may indicate statistically significant scores; however, the MCID is more useful in clinical practice for patient-

reported outcomes. Cleland et al. reported the MCID for the SSS as 0.36 and 0.10 for the symptoms subscale and functional subscale, respectively (2012). Moojen et al. reported that a mean treatment satisfaction scale score of 2.5 or less is clinically significant for patients undergoing surgery (2010).

The SSS is a highly reproducible measure when assessing the specific neuroischemic features of LSS (Pratt et al., 2002). As a disease specific questionnaire, the SSS captures information on the primary concerns of spinal stenosis; however, a limitation is that the SSS does not capture information on other areas of HRQL that may affect the patient's condition.

Centre for Epidemiologic Studies Depression Scale

The Centre for Epidemiologic Studies Depression (CES-D) Scale was administered to participants in the Alberta LSS Study to assess the degree of possible depressive symptoms. The CES-D Scale is a 20-item self-report scale that measures depressive symptoms of non-psychiatric persons. Participants answer questions regarding the frequency and length of depressive moods, thoughts or feelings within the past week. Response options for each item are on a 4-point Likert scale with scores ranging from 0 to 3. A response of '0' refers to 'rarely or none of the time'; '1' refers to 'some or little of the time'; '2' refers to 'moderately or much of the time' and '3' refers to 'most or almost all the time.' Questions 4, 8, 12, and 16 are worded affirmatively; therefore, scores for these questions are calculated by subtracting from 3. The scores of all 20 items are summed to provide an overall score ranging from 0 to 60. Higher scores indicate a greater degree of depressive symptomology.

Research commonly supports that a score of 16 or higher is indicative of depression in the general population (Lewinsohn et al., 1997); however, an article by Turk et al. suggests that for detecting depression in chronic pain patients, a score of 19 should be used instead of the standard cut-off score of 16 (1994). Because a cutoff point of 19 provides a conservative estimate of the prevalence of depressive symptomology, there is a decreased chance of including false positive participants who are identified as having depression.

The CES-D has been validated using traditional methods, which supports its validity and reliability for the general and clinical population (Radloff, 1977; Lewinsohn et al., 1997). The Cronbach alpha value for internal consistency was high in the general population (0.85) and clinical population sampled (0.90) (Radloff, 1977). The test-retest correlation was reported as moderate (r=0.53) in a clinical population (Radloff, 1977). Validity studies have examined the degree to which CES-D scores agree with other depression questionnaires. Using the Hamilton rating scale, validity correlations range between 0.50 and 0.80 (Locke et al., 2009). The psychometric properties of the CES-D have not been validated in an LSS population.

Comorbidities Associated with LSS

Understanding the interaction between comorbidities associated with LSS is important for identifying key prognostic factors of surgical recovery within clinical practice and for further research. Until recently, comorbidities associated with LSS were poorly understood. Mofidi et al. researched the effects of concomitant comorbidity on patients who received decompression surgery for LSS using the Musculoskeletal Outcomes Data Evaluation and

Management Systems (MODEMS) questionnaire (2002). Using a retrospective cohort study, Mofidi et al. concluded that having two or more comorbidities after decompressive laminectomy surgery significantly affects pain and functional outcomes for patients with LSS ($p<0.001$) (2002). From the 56 patients enrolled in the study, the comorbidities were vast and included: 19 cases of lower limb osteoarthritis; 3 cases of rheumatoid arthritis; 7 cases of ischemic heart disease; 2 cases of Parkinson's disease; 2 cases of diabetes and 1 case each of peripheral vascular disease and cerebral vascular accident (Mofidi et al., 2002). The list of comorbidities highlights the prevalence of concomitant pathology for patients with LSS; however, since LSS typically occurs in older adults, these comorbidities may be age-related and not necessarily associated with LSS (Abbas et al., 2013).

Sinikallio et al. assessed disability and pain recovery using the ODI and SSS for 102 patients with LSS showing depressive symptoms on the Beck Depression Inventory (BDI) at 2 years follow-up (2010). The results of the longitudinal cohort study found that patients with elevated depressive symptoms were more likely to experience both pain and functional disability at both 3 months and 2 years follow up (Sinikallio et al., 2010). The 3 month post-operative results were maintained at 2 years follow-up, showing that coexistence of pain and disability predicted poorer satisfaction with surgical outcome for LSS treatment (OR ODI: 1.18; 95% CI: 1.04, 1.34; OR SSS Symptom Severity: 1.16; 95% CI: 1.02, 1.31) (Sinikallio et al., 2010).

Moreover, Battie et al. found that patients diagnosed with LSS had a greater prevalence of arthritis, migraines, HBP, and urinary incontinence compared to a general population

sample after adjusting for age and gender (2012). The study highlights the wide variety of comorbidities that are associated with LSS. In addition, Battie et al. found that patients with LSS are at increased risk of having one or more comorbidities (2012). Other research has shown that post-operative patients with LSS have worse physical function and body pain scores on the SF-36, a health status questionnaire, with increasing number of comorbidities compared to those with no comorbidities (Slover et al., 2006). The presence of one or more comorbidities may have a synergistic effect on decreased functional outcomes after surgery for LSS depending on the number of comorbidities the patient has.

Hypertension

In Canada, recent estimates suggest that 6 million (23%) Canadian adults are diagnosed with HBP (Robitaille et al., 2012). The prevalence of HBP in Canada is higher among women (24.3%; 95% CI: 24.2, 24.3%) than men (21.7%; 95% CI: 21.7, 21.8%) (Robitaille et al., 2012). Older age also increases the odds of developing HBP. The odds of both men and women aged 65-74 are 1.62 times greater for developing HBP compared to those aged 45-54 ($p<0.0001$) (W. Wang et al., 2006). Arterial HBP refers to the chronic elevation of BP against the walls of the arteries that may lead to increased morbidity and mortality (Foex & Sear, 2004). BP is a product of systemic vascular resistance and cardiac output (Foex & Sear, 2004). Pathology may arise in individuals with increased cardiac output, increased systemic vascular resistance, or both (Foex & Sear, 2004). In clinical practice, a BP greater than 140/90 mmHg on two or more occasions is considered arterial HBP (Foex & Sear, 2004). Elevated BP is the leading prognostic factor for death, accounting for 13% of all global deaths and is the strongest factor for lost years of healthy life (Robitaille et al., 2012).

Interestingly, it has been reported that 17% of Canadian adults with measured HBP are not aware of their condition; therefore, prevalence statistics from many large self-report surveys by Statistics Canada and Health Canada may be underestimated in publications from these agencies (Robitaille et al., 2012).

Measurement of BP is conducted using a sphygmomanometer and stethoscope, or more commonly, an automated machine. Accurate and reliable measurement of BP is crucial to identify the presence of HBP. When properly maintained, all medical devices have some degree of error that fall within an acceptable range. The primary sources of error when measuring BP include inadequate observer training, sphygmomanometer inaccuracy, and poor technique (O'Brien & O'Malley, 1990). Sphygmomanometer size may affect the pulse amplitude for manual BP measurement and disrupt the auscultatory method of manual measurement (K. Ng & Small, 1993). Research has also highlighted observer error, resulting in a tendency to record identical duplicate measurements, which in one epidemiological study contributed to a ±0.85 mmHg difference in BP measurement (Bennett, 1994). Another study compared the mean difference in BP measurement in a Colin 8800C device compared with the 'gold standard' method of manual auscultation of BP by two experienced professionals (Pergola et al., 2007). Using both the Colin device and manual auscultation method by each professional, a mean value from 3 BP measurements was calculated from 96 participants (Pergola et al., 2007). Good agreement between the Colin device and manual readings with at least 85% of the readings within 10 mmHg and 95% of the readings within 15 mmHg for both systolic and diastolic BP (Pergola et al., 2007). It is possible for small measurement errors to have a significant impact in a clinical

setting as well as in large epidemiological study (e.g. misclassification); therefore, it is important to ensure that BP devices are certified, frequently calibrated and that proper training is provided to those administering the BP measurement (O'Brien & O'Malley, 1990).

Hypertension as a Prognostic Factor for Surgical Outcome of LSS

Research has established that accompanying comorbid conditions have a negative impact on the surgical outcome of patients with LSS (Foulongue et al., 2012; Katz et al., 1999), but it is unknown whether that includes HBP. Reviewing other literature of chronic diseases reveals an association between HBP and HRQL in non-surgical patients (Ucan & Ovayolu, 2010; Poljicanin et al., 2010). Ucan and Ovayolu reported that patients with both obesity and HBP experienced a significantly lower score (mean 32.2, SD 0.9) on the physical component of the SF-36 compared to patients with obesity (mean 37.1, SD 1.5) and HBP (mean 34.2, SD 0.9) alone ($p=0.022$) (2010). This illustrates the significant impact of HBP on HRQL and the cumulative effect of patients having two health conditions. The low score for HBP on the SF-36 indicated that a patient's physical well-being was negatively affected by the condition. In the same study, patients with both diabetes and HBP (mean 34.3, SD 0.9) experienced lower scores on the physical component on the SF-36 compared to patients with diabetes (mean 36.6, SD 1.1) and HBP (mean 34.2, SD 0.9) alone (Ucan & Ovayolu, 2010).

Evidence from a longitudinal study in another patient population also supports that HBP reduces HRQL in women with vertebral fractures on the mini-Osteoporosis Quality of Life

Questionnaire (OQLQ) (Papaioannou et al., 2006). Data were analyzed for 1,129 post-menopausal patients with a mean age of 67.2 (SD 11.9) years registered in the Canadian Database of Osteoporosis and Osteopenia (CANDOO) (Papaioannou et al., 2006). Those with HBP were found to have consistently reduced HRQL across several domains of the mini-OQLQ by -0.2 to -0.5 points (Papaioannou et al., 2006). If HBP can decrease the HRQL in patients with rheumatologic disorders such as osteoporosis or vertebral fractures, then perhaps HBP will have a similar effect for patients with LSS.

Lotan et al. assessed the association between systemic disease and LSS in a study cohort of 537 patients with a mean age of 64 (SD 14) years (2008). Of the 537 patients with LSS, 23.2% suffered from HBP compared to 7.8% in the general population in Israel ($p=0.006$) (Lotan et al., 2008). The second most prevalent chronic condition in this patient sample was diabetes mellitus (13.6%), compared to 5.6% the general population ($p<0.001$) (Lotan et al., 2008). The authors acknowledged diabetes mellitus as a prognostic factor for HBP, but also found that HBP was an independent factor in the analysis (Lotan et al., 2008). Lotan et al. speculated that vascular impairment caused by diabetes mellitus and HBP may result in nervous injury, thus exacerbating the symptoms of LSS (2008). Battie et al. also assessed comorbidities associated with LSS from patients identified at the time of a CT or MRI scan in Calgary, Canada (2012). Of the 240 patients identified with LSS, 105 (43.7%) reported having HBP (Battie et al., 2012). The odds of having HBP was 1.70 times greater for patients with LSS compared to the general population sample after adjusting for age and sex (95% CI: 1.27, 2.28) (Battie et al., 2012). Given the increased prevalence of HBP within an LSS population and the burden HBP has on HRQL, it is possible that HBP impedes

surgical recovery. Further research and consideration should be given to patients with LSS and coexisting HBP to better understand the effects of these concomitant pathologies on surgical recovery.

The most recent study showing the association between HBP and LSS is a cross-sectional study with 526 LSS patients (Uesugi et al., 2013). Participants were divided into elderly (≥ 70 years; n=317), non-elderly (<70 years; n=209), male (n=271) and female (n=255) (Uesugi et al., 2013). A chi square test was used to identify group differences when compared to a control group from the general population in Japan. HBP was statistically significantly associated with age among males (n=44; 39.3%) ($p<0.01$) and females (n=34; 35.1%) ($p<0.01$) within the non-elderly group (Uesugi et al., 2013). In contrast, HBP was not statistically significant in male or female elders with LSS in this patient sample ($p=0.65$ and $p=0.10$, respectively). Uesugi et al. argue that HBP may assist in the progression of arteriosclerosis and the calcification of the posterior wall of the aorta, which increases the risk of progression of intervertebral disc degeneration (2013).

A systematic review has shown evidence for the association between aortic atherosclerosis and intervertebral disc degeneration resulting in low back pain (Kauppila, 2009). The long-term effects of intervertebral disc degeneration in the lumbar region may lead to the development of LSS (Urban & Roberts, 2003). In their discussion, Uesugi et al. describe a biologically plausible pathogenesis of how a systemic disease, such as HBP, can contribute to the development of LSS (2013). Combining the proposed pathogenesis by

Uesugi et al. (2013) with earlier research by Lotan et al. (2008) and Battie et al. (2012) provides a reasonable foundation for the current thesis study.

Chapter III: Methods

This is a secondary analysis of the Alberta Lumbar Spinal Stenosis Study, a prospective cohort study of patients with radiographic LSS who were identified as study candidates at the time of magnetic resonance (MR) or computed tomography (CT) imaging in one of four imaging centres in Calgary, Canada. From those enrolled in the Alberta LSS Study, analysis was conducted on 97 participants who underwent elective surgical treatment for LSS upon diagnostic confirmation.

Participants

Alberta Lumbar Spinal Stenosis Study

The primary study, the Alberta LSS Study, was a prospective longitudinal study assessing prognostic factors for health-related outcomes of LSS. Patients presenting with low back related problems were referred to one of four imaging centres in Calgary between April 2004 and May 2005, primarily by spine specialists and general practitioners. Those expressing interest in the study at the time of imaging who were also identified as having anatomic stenosis on their radiological report were candidates for the study (Battie et al. 2012).

Of those who received an imaging procedure, 2,296 (72.5%) provided consent to be contacted for study participation and to use their scans for future research. Of these, 1,178 (51.3%) were found to have some indication of LSS on imaging, and 800 (67.9%) were successfully contacted by telephone by Battie et al. (2012). Telephone interviews in the Alberta LSS Study were conducted by trained research assistants between May 2004 and

May 2011. Research assistants asked interview questions based on a standardized script. Participants unable to complete the telephone interview were sent interview questions via mail to be returned upon completion. The 617 (85.2%) participants who also provided written informed consent for the use of their Alberta Health data, as well as meeting the criteria for having the clinical syndrome of LSS were considered for the present study analysis. Inclusion criteria for determination of the clinical syndrome of LSS consisted of: 1) referral to lumbar imaging for suspected LSS, for which results were confirmatory, or diagnosis of LSS on their medical chart by a spine surgeon after imaging; 2) 40 years or older; 3) English speaking, and 4) resident within the Calgary Health region (2012). Exclusion criteria consisted of 1) no spinal malignancies, infections, inflammatory conditions or fractures, and 2) no active cancer for which metastases were suspected (Battie et al., 2012). The study was approved by the Research Health Ethics Boards of the University of Alberta and the University of Calgary.

Other inclusion criteria for our analysis consisted of participants who: 1) received surgery for LSS identified in interview records from the Alberta LSS Study and/or Alberta Health (AH) hospital or physician claims records; and 2) completed interviews both before and after surgery (Appendix D).

Surgical cases

Surgical cases were identified using both self-report data from the Alberta LSS Study (Appendix A) and Alberta Health administrative data. Participants were asked whether

they had surgery for LSS during their Alberta LSS Study telephone interview. Participants who reported having surgery for LSS also provided the approximate date of surgery.

The AH data set comprised two different data sources: hospital inpatient claims and physician claims. Surgical patients were identified from hospital claims data using surgical procedure codes from the Canadian Classification of Health Interventions Volume 3 (2012) (Appendix B). The identification of surgical patients was further supported if patients had a confirmed diagnosis of LSS from the hospital claims data. Surgical patients were identified when coded with a corresponding LSS surgical procedure. Surgical procedures used to treat patients with LSS include: decompressive laminectomy, discectomy, foraminectomy, and laminotomy. The corresponding procedure codes used to identify surgical cases are as follows: 1.SC.74 'spinal vertebrae, fixation'; 1.SC.75 'spinal vertebrae, fusion'; 1.SC.89 'excision total, spinal vertebrae'; 1.SE.53 'implantation of internal device, intervertebral disc'; 1.SC.80 'repair, spinal vertebrae'; 1.SE.87 'excision, partial, intervertebral disc' and 1.SE.89 'excision total, intervertebral disc'. Spinal fusion may have been performed if the surgeon concluded that decompression resulted in vertebral instability.

As a method to support the identification of LSS-related surgery using procedure codes, participants were identified if diagnosed for LSS in the AH data set. Two universal classification systems were used to identify patients diagnosed with LSS for that particular hospital admission. The International Classification of Diseases, Ninth Revision, Clinical Modification (ICD9-CM) and the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD10-CM) codes from hospital inpatient claims were used to

identify patients diagnosed with LSS. The ICD9/10-CM diagnostic codes pertaining to LSS identified participants with the disorder for that particular hospital admission. The ICD9-CM codes included 724.0 'spinal stenosis, other than cervical' and 724.00 'multiple sites'. The ICD10-CM codes included: M4800 'spinal stenosis, multiple sites in spine'; M4805 'spinal stenosis, thoracolumbar region'; M4806 'spinal stenosis, lumbar region' and M4807 'spinal stenosis, lumbosacral region'. Either an ICD9-CM or ICD10-CM code was considered sufficient to identify a diagnosis of LSS in the current study.

Post-Surgical Outcome Measures

The post-surgical outcome measures used in our study included the Oswestry Disability Index (ODI), the Swiss Spinal Stenosis (SSS) Questionnaire, both of which have been shown to be valid and reliable measures in previous research. Both the ODI and SSS were recommended for use within a symptomatic LSS patient population by Fairbank (2000) and Stucki et al. (1996), respectively. To establish clinical significance for LSS surgical patients in our study, the MCID is 12.8 units for the ODI, 0.36 units for the SSS Symptom Severity and 0.10 units for the SSS Physical Function (Copay et al. 2008; Cleland et al., 2012).

Hypertension: Prognostic Factor of Interest

Alberta LSS Study:

Of those included in the surgical cohort, participants with HBP were identified through self-report from the Alberta LSS Study. During the telephone interview, participants were asked about comorbidities, and current medication prescriptions to control comorbidities.

If a patient self-reported HBP or was taking medication to control HBP, then this patient was considered hypertensive.

Alberta Health:

Within the AH hospital claims data, participants with HBP were identified using both ICD9-CM and ICD10-CM codes. The ICD9-CM codes corresponding to HBP include: 401.0 'malignant essential hypertension'; 401.1 'benign essential hypertension' and 401.9 'unspecified essential hypertension'. The corresponding ICD10-CM code used was I10.0 'essential (primary) hypertension'. A code from either ICD9-CM or ICD10-CM was considered sufficient for identifying a participant with HBP.

Possible Confounding Factors

During each telephone interview, participants were asked a variety of questions regarding all aspects of their health. Responses were extracted and analyzed as possible confounders for the relationship between HBP and post-operative disability in LSS patients as measured by the ODI and SSS. Questions such as socio-demographic characteristics (age, gender, education, marital status, employment status), and back/leg signs and symptoms (symptom severity and duration, pain, physical function, claudication, walking ability) were collected during the interview. Additionally, participants were asked if they had received surgery for LSS, and if so, the date of surgery. Interviewers also gathered information on specific comorbidities and medications.

Information regarding participant comorbidity was collected from the Alberta LSS Study asking whether they had the following conditions: asthma, chronic bronchitis or emphysema, HBP, heart disease, diabetes, cancer, effects of a stroke, migraine headaches, Alzheimer's disease or any other dementia, urinary incontinence, bowel disorder, thyroid condition, or any other long-term condition diagnosed by the a healthcare professional. Additional comorbidity data from AH supplemented the available information from the primary study, which included: Alzheimer's disease; anemia; arthritis; asthma; bowel disorder; cancer; cerebrovascular disease; chronic bronchitis; congestive heart failure; chronic obstructive pulmonary disease; depression; diabetes; effects of stroke; emphysema; heart disease; HBP; urinary incontinence; kidney disease; liver disease; migraine headaches; myocardial infarction; obesity; peripheral vascular disease; stomach ulcer; thyroid disorder and vision disturbance.

Using a parsimonious approach, comorbidities affecting a similar biological system (e.g. respiratory system) were combined. Both the 'respiratory disorder' and 'heart disease' variables comprised comorbidities identified through the interview and administrative data. Participants were identified as having a respiratory disorder if they had any one of the following conditions: chronic obstructive respiratory disorder (COPD), asthma, bronchitis, or emphysema. Similarly, participants with heart disease were identified as having any one of the following conditions: cardiovascular disease, myocardial infarction, or congestive heart failure comorbidities.

Participants self-reported their current prescriptions and whether they were taken for back pain, which were categorized into the following: anti-depressants; muscle relaxants; narcotics; analgesics; sedatives and steroid medication. Participants were also asked a series of other standardized health measures including: the Centre for Epidemiologic Studies Depression (CES-D) Scale to measure depression; the Medical Outcomes Social Support (MOS) Survey to assess social support; the Health Utilities Index Mark 2 and 3 (HUI 2/3), a preference-based measure for HRQL, and the Oxford Claudication Score to assess walking speed.

Discrepancy Protocols and Case Verification

To verify the consistency, self-report and administrative data were merged into a single data set for analysis using a unique identifier. A variable was created to distinguish surgical participants who were identified by either the Alberta LSS Study or AH. After merging the data from the Alberta LSS Study and AH, protocols were set to ensure consistent management of discrepancies between both data sources. If a LSS surgical procedure code did not appear in the AH hospital claims data, then a patient was accepted into the surgical cohort as long as LSS surgery was self-reported. If a patient was not diagnosed with LSS in either the interview or administrative data but received surgical treatment for LSS, then this patient was accepted into the surgical cohort.

With respect to the presence of HBP, if a participant was identified as hypertensive from one data source but not the other, then the participant was deemed as having HBP. Identification from both sources was not required to establish HBP in a participant. Also, if

a participant either self-reported HBP or was prescribed medication to control HBP, then the individual was considered to have HBP. Lastly, if HBP was identified before the hospital admission date of surgery, then these patients were classified as having HBP.

For participants with multiple surgeries, the surgery closest to the enrollment in the study was used for analysis in the current study. Using the surgery closest to the enrollment date prevents the risk of including additional surgeries that may be a revision of the first. The varying nature of a revision surgery may not be an appropriate comparison against participants who received a single surgery.

Follow-up Time for Analysis

Previous research has examined the recovery times of patients surgically treated for LSS. Results show that patients report better recovery several months after surgery compared to shortly after their procedure (Thornes et al., 2011; Atlas et al., 2000). The surgical cohort in this thesis study had a range of follow-up times spanning 12-925 days. With consideration of prior literature, the follow-up times were stratified into two groups to account for the natural recovery of an invasive surgical procedure: those with a follow-up time of less than 6 months, and those with a follow-up time of 6 months or greater. Participants within each window of time were analyzed in the multivariable analyses.

Data Analysis

The scores of standard health measures were calculated using the appropriate algorithm. Missing data were calculated using mean imputation at an item level and not at

an individual score level. A valid summary score was calculated using mean imputation if less than 5 questions were missing on the ODI and SSS (Bono et al., 2007). The ODI or SSS summary score was considered lost to follow-up if more than 4 responses were missing. Participant responses to these questionnaires were grouped by BP status, and reported as units instead of percentages.

Descriptive Analysis

A descriptive analysis of the surgical cohort was completed, which contains baseline information such as demographics, comorbidities, and medications. Descriptive statistics for the overall surgical cohort (n=97) were stratified according to BP classification. An independent samples t-test was used to test BP group differences for continuous variables, and a chi-square test was used to test categorical variables. The mean and standard deviation were reported for continuous variables. If the distribution of a variable was skewed, both the median and interquartile range were reported. Categorical variables such as education and comorbidities were summarized as a proportion of the total n value. Effect size (ES) was calculated to quantify the magnitude of the treatment effect using health measure scores before and after surgery. The difference between the pre- and post-operative score divided by the SD of the pre-operative score was used to calculate the ES. All analyses were performed using SPSS, version 21 (SPSS, Inc., Chicago, IL, USA).

Univariate Analysis

A univariate analysis was performed using simple linear regression to determine the individual contribution of each potential confounding factor on both the ODI and SSS

follow-up scores in our LSS patient population. A function in SPSS calculates the magnitude, direction and statistical significance of the association with the selected outcome variable (e.g. ODI or SSS). Also provided in the univariate output are the coefficients (i.e. slopes of regression analysis, B, and standard error), p-value, and the 95% confidence interval for B. Significance was set at $p < 0.05$ and all regression tests were two-sided.

Multiple Linear Regression Analysis

The ODI and SSS questionnaires served as the outcome measures. Multiple linear regression (MLR) was used to examine HBP as a prognostic factor of surgical recovery for LSS. Potential confounders were included to control for HBP. Each model was built using a parsimonious approach for the inclusion of independent variables. Model assumptions for MLR can be found in the Appendix C.

Variable Selection and Order of Entry for MLR

In addition to HBP, other variables were entered in the MLR models based on biological plausibility or evidence from the literature of having confounding effects, as well as our univariate analysis for the relationship between HBP and post-operative disability. A total of 8 possible confounding variables were proposed for inclusion into the MLR models based on prior research, including: age; gender; categorized follow-up time; baseline ODI or SSS; depression on CES-D; living situation; diabetes and heart disease. The order of entry was based on the largest increases of the HBP beta coefficient. After using the forward selection and backward elimination techniques to remove variables with no effect on the beta coefficient for HBP, the proposed model included: age, gender, HBP, follow-up time,

pre-operative ODI, number of comorbidities, and CES-D. Statistical significance was set at $p < 0.05$ and all regression tests were two-tailed.

Prior consideration was given as to which baseline measure should be included in the regression model for each health questionnaire. The SSS Physical Function scale measures physical disability resulting from LSS and measures a closely related construct as the ODI, that is, physical disability resulting from low back pain. Given that the SSS Physical Function scale and ODI measure a similar construct, the ODI baseline score was used to adjust both the ODI and SSS Physical Function post-operative score. In contrast, questions on the SSS Symptom Severity scale support a construct directed toward neurological and pain symptoms resulting from LSS. Because the SSS Symptom Severity measures a different construct than the SSS Physical Function and ODI, the pre-operative Symptom Severity scale score was used to adjust for post-operative Symptom Severity.

Chapter IV: Results

Of the 617 consenting participants with available Alberta Health data, 108 (17.5%) reported having surgery for their back during the interview after CT or MR imaging. Fifty-three (49.1%) of the 108 participants also had surgical documentation in the AH data records for the Alberta LSS Study. Another 14 participants who did not report back surgery during their interviews, had documentation for back surgery in the AH data files. The exact agreement for surgery between the interview and the AH data was 54.5% (Table 4.1). Between the 2 data sources, self-report and hospital/physician claims, 122 participants were identified as having back surgery after the imaging date.

To evaluate the post-operative outcomes, participants had to have a pre- and a post-operative interview. Nineteen (15.6%) of the 122 participants did not have a pre-operative interview, and another 6 (4.9%) participants were excluded because the post-operative interview was either missing or was beyond the 2-year timeframe of the study. Ninety-seven participants had surgery with both a pre-operative and follow-up interview and comprised the surgical cohort for our analysis (Appendix D).

Identification of Hypertensive Cases: Of the 97 surgical participants, 46 (47.4%) were classified as having high blood pressure (HBP) by either self-report of hypertension (n=46) or anti-hypertensive medication (n=25) prior to surgery. Of the 46 participants who were identified in the interview, 22 also had documented HBP in the AH records. Another 3 participants who did not report HBP during the interview but did have documented HBP in the AH records prior to surgery were identified (ICD9: 401.0, 401.1, 401.9). The exact

agreement for pre-existing HBP between the Alberta LSS Study and AH data was 44.4% (95%CI: 28, 61%; n=22) (Table 4.2).

Of the 97 participants in the surgical cohort, there were slightly more women (n=52; 53.6%) than men (Table 4.3). The HBP group included 28 (57.1%) females, and the non-HBP group included 24 (50.0%) females (p= 0.481). The mean age of the surgical cohort was 71.8 (SD 12.9) years, and those with HBP were older (76.8 (SD 11.4) years) than non-HBP participants (66.7 (SD 12.4) years) (p<0.001). Participants between the ages of 80-84 years had the highest proportion of HBP (n=11; 22.4%), followed by those between 75-79 years (n=9; 18.4%) and those between 85-89 years (n=7; 14.3%) (Table 4.4).

Based on self-report and AH data, participants in the surgical cohort had a mean number of 2.3 (SD 1.9) comorbidities (Table 4.3). Forty-one (42.3%) participants had 0-1 comorbidities, 48 (49.5%) had 2-3 comorbidities and 8 (8.2%) had 4-8 comorbidities. Participants without HBP (< 140/90 mmHg) had significantly fewer (1.7, SD 1.2) comorbidities than the HBP participants (2.9, SD 2.2) (p=0.001). The three most prevalent conditions for the HBP group were heart disease (n=18; 36.7%), urinary incontinence (n=17; 34.7%) and diabetes mellitus (DM) (n=12; 25.0%). The most common conditions for the non-HBP group were depression (n=20; 41.7%), heart disease (n=11; 22.9%) and urinary incontinence (n=9; 18.8%). Looking at specific conditions, participants with HBP had a higher proportion of participants with DM (n=12; 75.0%) than the non-HBP group (n=4; 25.0%) (p=0.032) and a higher proportion of thyroid disorders (n=10; 83.3%) than the non-HBP group (n=2; 16.7%) (p=0.015).

Depression was analyzed in the univariate and regression models using the CES-D scale. Information was also available for participants with documented antidepressant medication in the AH data file. Twenty-six (53.1%) participants with HBP reported a score above the threshold of 19 for depressive symptomology on the CES-D scale with a mean score of 18.8 (SD 9.0). An additional 2 (4.1%) hypertensive participants were documented for depression from AH records, although their CES-D scores were less than 19. Of the 26 (53.1%) hypertensive participants with depressive symptomology on the CES-D, 7 (26.9%) had documented depression and 8 (30.8%) were taking antidepressant medication in the self-report data file. Excluding those with both HBP and depressive symptomology (n=26), no other hypertensive participants were taking antidepressant medication. Twenty-one (43.8%) participants without HBP reported a score above the threshold of 19 for depressive symptomology with a mean CES-D score of 19.8 (SD 11.0). Of the 21 (43.8%) participants without HBP, 13 (61.9%) were also documented for depression and 12 (57.1%) reported taking antidepressant medication. No group differences between the BP groups were seen on the CES-D (p=0.359). Based on documented depression from AH data (p=0.021) and self-report antidepressant medication use (p=0.032), depression was more prevalent among participants without HBP (Table 4.3).

The pre-operative and post-operative time were analyzed for the surgical cohort. The median pre-operative time was 4.1 (IQR 1.0 – 7.3) months whereas the median follow-up time was 7.3 (IQR 5.4 – 11.7) months. Based on evidence looking at recovery milestones, participants were grouped into 2 follow-up time categories for the regression analysis

(Thornes et al., 2011; Atlas et al., 2000), less than 6 months (n=23) and greater than or equal to 6 months (n=74).

Surgical Characteristics

Because details regarding the surgical procedure were not collected during the interview, surgical information was only available for 51 (52.6%) participants with surgery recorded in the AH data. The demographic characteristics of this subgroup did not differ from other participants in the cohort (n=46). The mean age was 71.4 (SD 13.6) years (p=0.749) and 29 (56.9%) were female (p=0.128). Twenty-two (43.1%) participants had pre-existing HBP (p=0.129). The median length of hospital stay was 5.0 (IQR 3.0-8.0) days for the 51 participants. Decompressive laminectomy accounted for nearly half of the surgical procedures (n=25, 49.0%). The second most common surgical procedure was spinal fusion (n=23, 45.0%).

The median pre-operative interview time; however, was shorter for the 51 participants (2.8 (IQR 0.4 – 5.6)) compared to the other 46 participants in the surgical cohort (5.2 (IQR 1.8 – 9.9)) using a Mann-Whitney U non-parametric test (p=0.129). The median follow-up time was not statistically different from the 51 participants (6.8 (IQR 5.5 – 11.8)) compared to the other surgical participants (8.0, IQR 5.3 – 11.7) (p=0.617).

Surgical Complications: As with surgical procedure information, details regarding surgical complications following surgery were available for 51 (52.6%) participants (Appendix E). Twenty (39.2%) participants experienced at least one post-surgical complication, which we

defined as a hospital re-admission less than 30 days after hospital discharge for LSS surgery. Some participants reported more than one complication per hospital re-admission. Eight (40.0%) of the 20 participants who experienced post-surgical complication were hypertensive. The most frequent complications for decompressive laminectomy were musculoskeletal (n=3, 5.9%), integumentary-related (n=3, 5.9%) and gastrointestinal (n=3, 5.9%). The next most common complications for decompressive laminectomy surgery were spine-related (n=2, 3.9%) cardiovascular (n=2, 3.9%) and vision-related (n=1, 2.0%).

The most common post-surgical complication for spinal fusion was spine-related (n=7, 13.7%), including excessive low back pain. Other complications for spinal fusion included: cardiovascular (n=2, 3.9%); integumentary-related (n=2, 3.9%); depressive or anxiety-related (n=2, 3.9%); musculoskeletal (n=2, 3.9%). Participants who underwent fusion surgery did not experience vision-related or gastrointestinal complications. No complications were identified for the spinal excision or spinal fixation procedures.

Health Outcomes

Oswestry Disability Index

The mean pre-operative ODI score for this cohort was 59.0 (SD 17.0), representing severe disability that affects activities of daily living (Table 4.5). No pre-operative group differences existed between the HBP group (mean 58.9, SD 18.7), and the group without HBP (mean 59.0, SD 15.1) (p=0.976).

The mean post-operative ODI score for the cohort was 29.4 (SD 17.3). When grouped by BP status, the mean post-operative ODI score for HBP group was 30.1 (SD 17.7), and the mean post-operative score was 28.7 (SD 17.1) for the non-HBP group (p=0.699) (Table 4.5). Both post-operative ODI scores represent moderate disability affecting the participant's mobility, social life, and ability to work.

The mean ODI difference over time, comparing the pre-operative and post-operative score, was 29.1 (95% CI: 23.6, 34.6) units for the HBP group and 30.3 (95% CI: 25.6, 35.1) units for the non-HBP group (p=0.575). Both groups showed a clinically meaningful difference when comparing pre-operative to post-operative ODI scores (MCID=12.8; Copay et al., 2008). No clinically meaningful differences existed between BP groups either pre-operative or post-operatively The ES was 1.73 (95% CI: 1.39, 2.06), which indicated that surgical intervention had a large difference for the study cohort. The mean ODI score for participants with a follow-up time of less than 6 months was 36.0 (SD 17.6) and 6 months or greater was 27.3 (SD 16.8, p=0.035). The ES for follow-up less than 6 months was 1.15 (95% CI: 0.52, 1.77) as compared to the follow-up that was 6 months or greater (ES=1.95; 95% CI: 1.56, 2.35).

SSS Symptom Severity

The mean pre-operative score for Symptom Severity was 2.1 (SD 0.65) units. Similar to the ODI scores, no group differences were seen between the mean pre-operative scores for the HBP group (2.2, SD 0.72) and the non-HBP group (2.1, SD 0.59) (p=0.910).

At follow-up, participants in the HBP group had a mean post-operative score of 1.4 (SD 0.83). Participants in the non-HBP group did not have a statistically different mean post-operative score (mean 1.4, SD 0.79, p=0.910) (Table 4.5).

The mean difference over time, calculated using a paired samples t-test, was 0.75 (95% CI: 0.50, 1.0) units for the HBP group and 0.73 (95% CI: 0.47, 1.0) units for the non-HBP group. The overall difference between pre- and post-operative scores shows a clinically meaningful difference for both BP groups (MCID = 0.36; Cleland et al., 2012). The overall ES was 1.0 (95% CI: 0.70, 1.30), which represents a large difference between the pre- and post-operative scores. Regardless of BP status, the mean post-operative Symptom Severity scale score for participants with a follow-up time of greater than or equal to 6 months was 1.36 (SD 0.82), and for participants followed-up less than 6 months the mean score was 1.61 (SD 0.73) (p=0.189). The ES for follow-up less than 6 months was 1.15 (95% CI: 0.52, 1.77) compared to the follow-up that was 6 months or greater (ES=1.95; 95% CI: 1.56, 2.35), both indicative of large change associated with the surgical intervention.

SSS Physical Function

The mean pre-operative score on the Physical Function scale was 2.5 (SD 0.63) units. Overall pre-operative Physical Function scores did not differ between the HBP (mean 2.5, SD 0.61) and non-HBP (mean 2.4, SD 0.64) groups (p=0.151) (Table 4.5).

The mean post-operative score in the HBP group was 1.9 (SD 0.74), and in the non-HBP group the mean post-operative score was 1.8 (SD 0.64). No statistically significant difference was seen in post-operative scores based on BP status (p=0.292).

The mean difference for the HBP group was 0.64 (95% CI: 0.43, 0.87) and the mean difference for the non-HBP group was 0.59 (95% CI: 0.36, 0.82). The overall difference between pre- and post-operative scores shows a clinically meaningful difference for both BP groups (MCID =0.10; Cleland et al., 2012). The ES for Physical Function was less than the ES for the ODI (0.92, 95% CI: 0.62, 1.22). Physical Function scale scores showed greater improvement at greater than or equal to 6 months compared to scores collected less than 6 months. Regardless of BP status, the mean post-operative Physical Function scale score for participants with a follow-up time greater than or equal to 6 months was 1.78 (SD 0.70), and for participants followed-up less than 6 months the mean score was 2.02 (SD 0.65) (p=0.148). The ES for follow-up less than 6 months was 0.48 (95% CI: 0.10, 1.07), which shows a moderate practical significance for surgery whereas the ES for greater than 6 months follow-up (ES=1.07; 95% CI: 0.72, 1.43) shows a large practical significance (p=0.714).

Linear Regression Analysis

HBP was not a significant independent prognostic factor of post-operative disability after LSS surgery at the univariate level (p=0.699) (Appendix F). The mean unadjusted post-operative ODI score was 1.4 (95% CI: -5.7, 8.5) units higher for participants with pre-existing HBP compared to those without HBP.

Other significant variables at the univariate level for post-operative ODI included the CES-D and follow-up time. Participants with depressive symptoms on the CES-D scale (scores 19 or greater) had worse post-operative ODI scores by 12.1 units compared to those with CES-D scale scores less than 19 (95% CI: 5.4, 18.7, p=0.001). Participants followed-up greater than or equal to 6 months after surgery had an improvement of 8.7 units on the post-operative ODI questionnaire compared to participants followed-up less than 6 months (95% CI: -16.8, -0.63, p=0.035). Each additional comorbidity worsened post-operative ODI scores by 7.3 units (95% CI: 1.6, 13.0); however, variables such as age, gender, living situation, diabetes, and heart disease were not associated with post-operative ODI score.

By comparison, both the Symptom Severity (Appendix G) and Physical Function (Appendix H) scales both had smaller adjusted HBP coefficients than the ODI. The mean unadjusted Symptom Severity scale score was 0.02 units higher for participants with pre-existing HBP compared to those without HBP (95% CI: -0.31, 0.35, p=0.113). On the Physical Function scale, the mean unadjusted score was 0.15 units worse for participants with pre-existing HBP compared to those without the condition (95% CI: -0.13, 0.44, p=0.292).

The univariate analysis for the Symptom Severity scale had one statistically significant variable. Participants with cancer (n=12) scored 0.53 units worse on the post-operative Symptom Severity scale compared to those without cancer (95% CI: 0.04, 1.00, p=0.033).

No independent variables showed a statistically significant relationship with the post-operative Physical Function scale.

Multiple Linear Regression (MLR) Analysis

A MLR model was developed based on previous findings from the literature that support the inclusion of variables confounding the relationship between HBP and surgical disability using the post-operative ODI score (Table 4.6). First, age and gender were both forced into the model to control for their effects on the relationship between HBP and post-operative disability. Next, follow-up time was included in the proposed model since post-operative ODI scores captured at greater than or equal to 6 months following surgery differed from scores captured at less than 6 months.

Pre-operative ODI was included in the proposed model because of its high correlation with the outcome. This was followed by the inclusion of the potential confounders: diabetes, number of comorbidities and CES-D. Within our analysis, the number of comorbidities and depression were shown to be confounders since the inclusion of each variable changed the HBP coefficient by 15%; therefore, both variables were included in the model (Bliss et al., 2011). Because diabetes did not change the HBP coefficient by 15% and did not have a statistically significant effect in the multiple linear regression analysis, it was excluded from the model.

After controlling for age, gender, follow-up time, pre-operative ODI, number of comorbidities and depression, the post-operative ODI score was 1.32 units higher for

participants with pre-existing HBP compared to those without HBP (95% CI: -5.64, 8.28) (Table 4.6; Appendix I). No clear effect of HBP was seen on post-operative ODI following LSS-related surgery and the result was not statistically significant (p=0.747).

A single construct outlier was identified when considering the follow-up time. The outlier was a participant who had a single follow-up interview at 0.4 months, which was during the acute phase of recovery. When this case was removed and re-analyzed within the MLR analysis, no significant changes in the regression or effect size estimates were seen. This case was left in the final analysis.

Another MLR model was developed that used the difference between pre-operative and post-operative ODI scores as the dependent variable. This was performed because, the standardized beta (β) indicated that pre-operative ODI score had the largest effect to explain the post-operative ODI score (β=0.36) (Appendix J). The independent variables in this change model remained in the same order. The unstandardized coefficient for HBP was -3.40 and remained not significant (95% CI: -11.45, 4.65, p=0.403). Analysis of the change model showed no large changes in magnitude or significance in the coefficients for HBP; thus, the proposed model was chosen as the final model.

A similar MLR model was constructed for the SSS Symptom Severity scale (Table 4.6; Appendix K). No clear effect of HBP was seen on the post-operative Symptom Severity scale when adjusted for age, gender, follow-up time, pre-operative Symptom Severity, number of comorbidities and CES-D. Post-operative Symptom Severity scale scores were 0.03 units

higher for participants with pre-existing HBP compared to those without the condition HBP (95% CI: -0.33, 0.39, p= 0.886). Pre-operative Symptom Severity was not statistically significant in the Symptom Severity model (p=0.067). No variables showed statistical significance in the Symptom Severity scale model.

As with the SSS Symptom Severity scale, a MLR model was constructed for the Physical Function scale (Table 4.6; Appendix K). HBP did not have a statistically significant effect on the post-operative Physical Function scale after controlling for age, gender, follow-up time, pre-operative ODI, number of comorbidities and CES-D. The post-operative Physical Function score was 0.17 units higher for participants with pre-existing HBP compared to those without HBP (95% CI: -0.15, 0.49, p= 0.302).

Power Calculation

A post-hoc power calculation was performed to determine if the number of HBP events within the surgical cohort was sufficient to validate the post-operative recovery outcomes. The aim for the calculation is to achieve a power of 80% with alpha set at 0.05 and two-tailed. With seven variables included in the MLR analysis, the post-hoc calculation revealed a power that was much less than anticipated (6.6%), suggesting an insufficient sample size to detect an effect.

Table 4.1 Surgical case ascertainment using self-report data and Alberta Health administrative data from the Alberta Lumbar Spinal Stenosis Study

		Alberta Health		
		Identified	**Not Identified**	**Total**
Alberta Lumbar Spinal Stenosis	**Identified**	53	55	108
	Not Identified	14	495	509
	Total	67	495	617

Table 4.2 Agreement* of surgical cases with pre-existing hypertension using self-report data and Alberta Health administrative data from the Alberta Lumbar Spinal Stenosis Study

		Alberta Health		
		Identified	**Not Identified**	**Total**
Alberta Lumbar Spinal Stenosis	**Identified**	22	24	46
	Not Identified	3	48	51
	Total	25	72	97

*** Kappa Agreement: 44.4% (95% CI: 28, 61%)**

Table 4.3 Baseline characteristics

Characteristics	n (%) or Mean ± SD	n (%) or Mean ± SD		P-value
	Overall Surgical Cohort (n=97)	With Pre-existing Hypertension (n=49)	Without Pre-existing Hypertension (n=48)	
Age (Mean, SD)	71.8 ±12.9	76.8 ± 11.4	66.7 ± 12.4	<0.001
Gender, female	52 (53.6)	28 (57.1)	24 (50.0)	0.481
Education:				
Completed highschool	87 (89.7)	41 (83.7)	46 (95.8)	0.049
Martial Status:				0.878
Married/Common Law	68 (70.1)	34 (69.4)	34 (70.8)	
Other	29 (29.9)	15 (30.6)	14 (29.2)	
Living Situation:**				
Live alone	17 (17.5)	9 (18.4)	8 (16.7)	0.826
Living with another person	79 (81.5)	40 (81.6)	39 (81.3)	
Follow-up Time (Median, IQR) (months)	7.3, 5.4 - 11.7	8.5, 5.4 - 12.1	6.8, 5.3 - 10.6	0.423
Comorbidity: mean (SD)	2.0 (1.7)	2.5 (1.9)	1.5 (1.1)	0.001
Heart Disease	28 (28.9)	18 (36.7)	10 (20.8)	0.084
Depression	28 (28.9)	9 (18.4)	19 (39.6)	0.021
Incontinence	24 (25.3)	16 (32.7)	8 (16.7)	0.067
Diabetes	16 (16.8)	12 (24.5)	4 (8.3)	0.032
Thyroid Disorder	12 (12.4)	10 (20.4)	2 (4.2)	0.015
Cancer	12 (12.4)	8 (16.3)	4 (8.3)	0.232
Bowel disorder	10 (10.3)	7 (14.2)	3 (6.3)	0.193
Obesity	10 (10.3)	6 (12.2)	4 (8.3)	0.383
Respiratory Disorder	9 (9.3)	6 (12.2)	3 (6.3)	0.309
Arthritis	8 (9.4)	3 (6.1)	5 (10.4)	0.569
Stroke	3 (3.1)	2 (4.1)	1 (2.1)	0.488
Peripheral Vascular Disease	2 (2.1)	2 (4.1)	0	0.129
Stomach Ulcer	2 (2.1)	1 (2.0)	1 (2.1)	0.988
Alzheimers	1 (1.0)	1 (2.0)	0	0.320
Anemia	1 (1.0)	1 (2.0)	0	0.320
Kidney Disease	1 (1.0)	1 (2.0)	0	0.320
Vision Disturbance	1 (1.0)	1 (2.0)	0	0.286
Liver Disease	0	0	0	N/A
CES Depression Scale:				
Depressed (score of 19 or higher) (%)	47 (48.5)	26 (53.1)	21 (43.8)	0.359
Medications: (mean±SD)	3.2 ±1.4	3.1±1.4	3.4±1.3	0.200
Analgesics	87 (89.7)	45 (91.8)	42 (87.5)	0.483
Anti-depressants	25 (25.8)	8 (16.3)	17 (35.4)	0.032
Any medication taken for back pain	91 (93.8)	44 (89.8)	47 (97.9)	0.097
Steroids	9 (9.3)	8 (16.3)	1 (2.1)	0.016
Muscle Relaxants	30 (30.9)	13 (26.5)	17 (35.4)	0.344
Narcotics	46 (47.4)	23 (46.9)	23 (47.9)	0.923
Sedatives	26 (26.8)	9 (18.4)	17 (35.4)	0.058

***P-values calculated using independent samples t-test for continuous variables, chi-square test for categorical variables, and Mann-Whitney U non-parametric test for Follow-up Time**

**** Participants without pre-existing hypertension (n=47); Overall surgical cohort (n=96)**

Table 4.4 Distribution of 49 hypertensive participants in surgical cohort by 5 year age groups

Age in Years	Men (n=21)	Women (n=28)	Total (%)
40-44	0	0	0 (0)
45-49	0	0	0 (0)
50-54	3	2	5 (10.2)
55-59	0	0	0 (0)
60-64	0	3	3 (6.1)
65-69	2	2	4 (8.2)
70-74	3	2	5 (10.2)
75-79	3	6	9 (18.4)
80-84	4	7	11 (22.4)
85-89	5	2	7 (14.3)
90-94	1	3	4 (8.2)
95-99	0	1	1 (2.0)

Table 4.5 Health measure summary scores, effect size and mean difference

Health Measure	Overall n	Pre-operative Score (mean (SD))		P-Value	Overall n	Post-operative Score (mean (SD))				P-Value	Effect Size† (95% CI)	Mean Difference (95% CI)	
		With Pre-existing Hypertension (n=49)	Without Pre-existing Hypertension (n=48)			n	With Pre-existing Hypertension	n	Without Pre-existing Hypertension			With Pre-existing Hypertension	Without Pre-existing Hypertension
Oswestry Disability Index	97	58.9 (18.7)	59.0 (15.1)	0.976	95	47	30.1 (17.7)	48	28.7 (17.1)	0.699	1.73 (1.39, 2.06)	29.10 (23.60, 34.60)	30.30 (25.60, 35.10)
Swiss Spinal Stenosis, Symptom Severity	97	2.2 (0.72)	2.1 (0.59)	0.910	94	46	1.4 (0.83)	48	1.4 (0.79)	0.910	1.00 (0.70, 1.30)	0.75 (0.50, 1.00)	0.73 (0.47, 1.00)
Swiss Spinal Stenosis, Physical Function	97	2.5 (0.61)	2.4 (0.64)	0.151	92	45	1.9 (0.74)	47	1.8 (0.64)	0.292	0.92 (0.62, 1.22)	0.64 (0.43, 0.87)	0.59 (0.36, 0.82)

†Effect Size = (Pre-operative - Post-operative score)/Standard Deviation

Table 4.6 The relationship between high blood pressure and post-operative outcomes after lumbar spinal stenosis surgery

Health Measure	Univariate Analysis		Multivariable Analysis[§]	
	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value
Oswestry Disability Index	1.39 (-5.72, 8.49)	0.699	1.32 (-5.64, 8.28)	0.706
Swiss Spinal Stenosis, Symptom Severity	0.02 (-0.31, 0.35)	0.113	0.03 (-0.33, 0.39)	0.886
Swiss Spinal Stenosis, Physical Function	0.15 (-0.13, 0.44)	0.292	0.17 (-0.15, 0.49)	0.302

[§]Adjusting for age, gender (female), follow-up time (<6months), pre-operative score, number of comorbidities, and depression (Centre for Epidemiologic Studies Depression scale; cut-off score 19+)

Chapter V: Discussion

The findings from our community-based cohort study suggest that pre-operative HBP does not affect short and long-term recovery after surgery for LSS. Functional recovery, as measured by the ODI, is not dependent upon pre-operative high blood pressure. In spite of a high proportion of patients who reported or had documented HBP (50.5%), HBP did not influence the functional recovery after surgery. Regardless of blood pressure status, large gains in function and reduction of symptoms were seen up to 2 years after surgery for LSS.

Our results are congruent with the findings of others who reported that HBP did not affect the outcomes after surgery for LSS (Slover et al., 2006; Rihn et al., 2015). A large prospective cohort study of 1329 patients who received lumbar spine surgery for LSS and spondylosis found that HBP had no statistically significant effect on disability and general health as measured by the SF-36 bodily pain scale, physical function scale and physical component summary (PCS) at 1 year follow up (Slover et al., 2006). In similar research, Rihn et al. reported that HBP was not associated with post-surgical disability using the ODI (2015). The cohort of 150 older aged patients from the Spine Patient Outcomes Research Trial received surgery for LSS and degenerative spondylolisthesis (Rihn et al., 2015). Although Rihn et al. compared participants based on age, 80 years or older versus 79 years or younger, HBP in both groups was not significant (2015). For those 80 years or older (mean gain 18.5, SE 1.8), HBP was not associated with post-surgical disability (ODI) compared to a group of younger patients aged 79 years or younger (mean gain 21.3, SE 0.5, p=0.69) over 4 years follow-up (Rihn et al., 2015). The mean gains for both age groups

were lower than our study, which saw a mean gain of 29.1 (95% CI: 23.6, 34.6) units for the HBP group and 30.3 (95% CI: 25.6, 35.1) units for the non-HBP group on the ODI.

Although HBP does not appear to affect recovery after surgery for LSS, others have reported that HBP is associated with HRQL in patients with LSS (Battie et al., 2012; Lotan et al., 2008; Uesugi et al., 2013). Battie et al. examined overall health in participants with LSS and associated comorbidities (2012). Using the HUI3, a generic health measure, they reported that HBP in patients (mean age 65.9 (SD 11.4) years) with LSS had lower HUI3 scores (mean 0.60, SD 0.28) than the general population without back pain (mean 0.88, SD 0.19) after adjusting for age and gender (1=perfect health) (Battie et al., 2012). Results from Battie et al. also showed that the odds of having HBP were 1.70 times greater for participants with LSS compared to the general population (95% CI: 1.27, 2.28) (2012). The discrepancy with the current study may be due to a few factors. First, we used a spine-specific outcome measure, whereas Battie et al. used a generic measure (i.e. HUI3) (2012). A generic health measure such as the HUI3 evaluates overall health and is more likely responsive to the effect of other conditions than a spine-specific measure (i.e. ODI). Second, it may be that the surgical LSS patient population differs from the overall LSS patient population. There may have been a selection bias whereby surgeons selected only healthy patients medically stable for elective LSS surgery. It is also possible that LSS surgical patients did not respond positively to conservative treatment or may have had a more severe condition.

Similar to the findings from Battie et al. (2012), Uesugi et al. (2013) reported a high prevalence of HBP within LSS patients; however, a distinction from the current study is the selection of only surgical participants whose high proportion of HBP did not show statistical significance to LSS. Using a cross-sectional study that comprised non-surgical Japanese patients aged 70 years or younger (n=209), Uesugi et al. found that HBP was statistically significantly higher among male (n=44; 39.3%, $p<0.01$) and female patients (n=34; 35.1%, $p<0.01$) compared to the general population (n=2509) (2013). Methodological differences exist between the study by Uesugi et al. (2013) and the current one, which might explain why HBP was not associated with LSS outcomes. Because the findings by Uesugi et al. used a cross-sectional study design, the exposure and outcome are measured simultaneously making it difficult to establish a causal relationship between HBP and LSS (2013). In contrast, regression analysis within the current study controlled for confounding effects between HBP on post-operative disability, which is not possible for a cross-sectional study. The absence of adjusting for important factors may not provide a true estimate of the effect of HBP on recovery after surgery.

Given that LSS results from multiple causes, limited research has attempted to identify the pathophysiology of this degenerative disease, making it challenging to assess biological plausibility. Researchers have explored the biological mechanism for the development of LSS (Uesugi et al., 2013; Kauppila, 2009; Urban & Roberts, 2003). Uesugi et al. proposed that HBP might contribute to the progression of arteriosclerosis, calcifying the posterior wall of the aorta, which increases the risk of progression for intervertebral disc degeneration (2013). Further evidence from a systematic review supports the association

between aortic atherosclerosis and intervertebral disc degeneration (Kauppila, 2009), for which the long-term effects may lead to the development of LSS (Urban & Roberts, 2003). While this may be biologically plausible, it remains speculative and etiological research has yet to support the association of HBP and LSS. Establishing the pathophysiology may assist in identifying the determinants for LSS and advance this area of research

Although few studies have reported HBP in patients with LSS, evidence reported in similar conditions such as cervical spine myelopathy may provide some insight. The symptoms of this condition may result from ossification of the posterior longitudinal ligament or cervical disk herniation that compresses the spinal cord. With a prevalence of 605 per 1,000,000 in North America, cervical spine myelopathy is one of the most common neck conditions in older adults (Nouri et al., 2015; Maeno et al., 2015). Findings from a retrospective cohort study compared mean pre- and post-operative scores of motor and sensory function (Japanese Orthopedic Association (JOA) scale) in 100 participants across 4 age groups (50-59, 60-69, 70-79, and 80-89 years) with and without pre-operative HBP (Maeno et al., 2015). Patients with HBP had worse 1 year post-operative functional outcomes for hypertensive participants (n=44; 44.0%) following laminoplasty ($p<0.05$) than patients with normal BP regardless of age group (Maeno et al., 2015). Because the rate of HBP increased with older age, and despite age stratification, 10-year age groups may be long enough for HBP to serve as a confounding variable and show an artificial association with worse functional recovery (Maeno et al., 2015).

While earlier research did not directly assess the relationship between HBP and LSS, Katz et al. (1999) and Airaksinen et al. (1997) examined the effects of cardiovascular comorbidity on surgical outcomes in patients treated for LSS. HBP is regarded as a prognostic factor for CVD. The Framingham Study reported that women with HBP had a 150% chance of developing CVD than women without HBP (hazard ratio 2.5, 95%CI: 1.6, 4.1) (Vasan et al., 2001). Men with HBP had a 60% chance of developing CVD than men who were normotensive (hazard ratio 1.6, 95%CI: 1.1, 2.2) (Vasan et al., 2001). In a retrospective cohort study with 438 LSS patients, Airaksinen et al. showed that functional recovery was not statistically different for 29 (6.6%) patients with CVD (mean ODI 35.6, SD 19) 1 year after surgery compared to those patients without CVD (mean ODI 34.0, SD 18) (1997). Like our study, they used the ODI to measure disability over a short-term recovery period (Airaksinen et al., 1997). Similarly, Katz et al. (1999) followed 199 patients over 2 years after LSS-related surgery. The results from the multiple linear regression models showed that compared to greater cardiovascular involvement, those with mild cardiovascular involvement reported reduced LSS-related symptoms (SSS Symptom Severity) (coefficient 2.6, $p=0.01$), greater walking capacity (SSS Physical Function) (coefficient 2.7, $p=0.08$) and greater satisfaction (coefficient 3.7, $p<0.001$) 2 years after surgery (Katz et al., 1999).

Regardless of blood pressure status, our study found large functional improvements up to 2 years post-operatively. When comparing mean pre- and post-operative ODI scores, the surgical cohort showed a clinically meaningful difference for both BP groups (mean difference: HBP 29.1, 95% CI: 23.6-34.6; non-HBP 30.3, 95% CI: 25.6-35.1). It should be

acknowledged that no clinically meaningful differences for the ODI have been defined in surgical patients with LSS; however, a 12.8 point difference in the ODI has been defined as a clinically meaningful difference for non-surgical LSS patients (Copay et al., 2008). When adjusting for the effect of age, gender, follow-up time, pre-operative disability (ODI), number of comorbidities and depression (CES-D), we found that participants experienced disability improvements after surgical intervention. The gains were considered large (effect size 1.73), regardless of the 4 different types of surgery performed in this study group.

Although in-hospital complication rate was examined in a subset of the surgical cohort (53%), it did not differ between patients with HBP and those without HBP (p=0.927). The surgical complication rate in our study was 39 per 100 participants. Regardless of procedure, the number of post-surgical complications did not differ based on BP status nor surgery type when comparing laminectomy versus fusion (p=0.807). Overall, the most common post-operative complications were spine-related followed by musculoskeletal, integumentary-related, and gastrointestinal. While earlier research has not compared LSS–related surgical complications based on BP status, relatively lower post-surgical complications rates were reported by Deyo et al. after LSS surgery at a rate of 4.3 per 100 (n=32,152) (2010). A possible reason for this lower complication rate is the larger denominator when calculating the rate. Deyo et al. also documented complications as either cardiopulmonary resuscitation or repeat post-operative endotracheal intubation and mechanical ventilation, which is perhaps a more restrictive definition (2010).

HBP was the most common comorbidity in this surgical cohort which is reflective of the prevalence of HBP in the general population. In our cohort, the crude HBP rate was 50,515 per 100,000 participants and the median age was 73.0 (IQR: 62.3 – 82.0) years. Participants in the current study included those with ages ranging between 40-96 years. Older aged participants accounted for a higher proportion of those who identified with HBP (Table 4.4). Of the 49 hypertensive participants, 37 were aged 70 years or older, 11 of whom were between the ages of 80 and 84 years. The crude rate of HBP in the Canadian general population is 22,709 per 100,000, and as with our cohort, increases in age sees larger incremental changes of HBP rates (Robitaille et al., 2012). For example, the prevalence of HBP for adults aged 60-64 years is 43,300 per 100,000 whereas those aged 80-84 years have a HBP prevalence of 74,300 per 100,000, which is the highest 5 year age category in the Canadian general population (Robitaille et al., 2012). As with the Canadian HBP prevalence rates, our cohort saw the highest proportion of hypertensive participants between the ages of 80-84 years. Besides having a smaller sample size, a possible reason for lower HBP rates among older aged participants in our study may be due to selection bias, whereby surgeons may have selected relatively healthy patients who were medically stable.

While half of our study cohort had HBP, it was not a statistically significant prognostic factor that affected post-operative disability; however, other pre-operative factors were consistent with findings from the literature (Sobottke et al., 2015; Jansson et al., 2009; Airaksinen et al., 1997). Pre-operative ODI contributed 8.8% to the final ODI model. With other variables held constant in the model, the standardized coefficient revealed that a 1-

point increase in pre-operative ODI score was associated with a 0.38-point increase in ODI post score (95% CI: 0.16, 0.60). A cohort study using Spine Tango registry data evaluated post-surgical HRQL and pain relief outcomes using the Core Outcomes Measures Index (COMI) on 4768 patients and found that the odds of worse post-operative scores were 2.6 (95% CI: 2.38, 2.84) times greater per worse pre-operative response option (Sobottke et al., 2015). Other work that examined health status has also reported that pre-operative disability was a significant prognostic factor in explaining the 6 months ODI scores after LSS-related surgery (Ulrich et al., 2015; Mobbs et al., 2014; Weinstein et al., 2010; Atlas et al., 2000).

Participants were identified as having HBP from both interview and administrative data sources; however, there was a possibility that non-differential misclassification of HBP may have occurred. That is, the probability of HBP status being misclassified was independent of functional status. Non-differential misclassification of being classified as having or not having HBP would have increased the similarity between the 2 groups, resulting in an underestimate of the true strength of the association between HBP and functional outcome. Differential misclassification may have occurred with possible recall bias during the interview. Because both sources were used, be it interview or administrative data, differential misclassification due to recall bias cannot be ruled out. Given that the kappa agreement was considered 'moderate' agreement (Viera & Garrett, 2005), it was likely that differential misclassification was not a significant consideration.

The prevalence of depression in this cohort (n=47; 48.5%) was similar to what was reported in other similar populations (Sinikallio et al., 2009; Lubelski et al., 2015). We decided to use a cutoff point of 19 rather than 16 on the CES-D scale because the findings by Turk et al. demonstrated that a higher cutoff score for chronic pain patients identified depression in chronic pain patients (1994). Using a cutoff point of 19 provides a conservative estimate of the prevalence of depressive symptomology, which decreases the likelihood of including false positives and may underestimate the unstandardized coefficient statistic for depression. In the development stages of the multiple linear regression model, depression was shown to confound the effects of HBP on post-operative ODI using the 15% rule of thumb (Bliss et al., 2011); therefore, depression was included in the model to control for its confounding effects. Because the number of comorbidities variable met the criteria for confounding, it was also included.

A strength of this study was the use of data from multiple sources, which provided quality information for analysis. Data available from the Alberta LSS Study included a patient survey supplemented by administrative data from Alberta Health. This dual source of health information provided an enriched data set from the perspective of surveyed participants and a provincial health organization. Data redundancy is useful when one data set is missing essential participant information that can be captured in the other.

Another strength of this study is that the surgical cohort was identified at the time of referral for imaging. In turn, candidates were recruited at the time of MR imaging rather than when they presented for surgery (Soriano et al., 2010; Lotan et al., 2008; Uesugi et al.,

2013). Using MR imaging for participant enrollment reduced the potential for selection bias by the physician.

The longitudinal study design is another strength of our research. Because the survey data were recorded during multiple interview visits, the opportunity for recall bias was minimized, which is especially important for time-sensitive variables such as LSS surgical dates. With any longitudinal study, losses to follow-up are a concern. This study had a high follow-up rate within the surgical cohort. Losses to follow-up resulted from missing post-operative scores on the ODI (n=2; 2.1%), SSS Symptom Severity scale (n=3; 3.1%) and SSS Physical Function scale (n=5; 5.2%).

Although our study had a high follow-up rate, the small number of participants in this cohort was a concern. Given the small number of participants in the current study and the possibility of chance variation, it is possible that a similar analysis using a larger cohort may have yielded different results.

In most cases, HBP is a chronic condition that is managed with medications, diet, and exercise. The effects of HBP affect the vascular system over the long-term. Defining HBP in terms of severity rather than a dichotomous variable could provide valuable information on the relation of HBP and recovery. The current study did not control for the severity of HBP that is often controlled through medication and improved lifestyle changes, nor did our research control for the number of years that each participant was hypertensive prior to surgery. This may have resulted in a selection bias since only those patients with

controlled HBP were selected for elective LSS surgery. It is possible that participants with uncontrolled HBP have worse post-operative disability compared to patients whose HBP is well controlled.

Another limitation of this study was that participants were selected based on surgeries performed in the province of Alberta and did not include procedures outside of Canada. As a result of this selection bias, some participants who fit the study selection criteria and who received LSS-related surgery were not included in the study cohort. It is not possible to determine the actual number of participants who sought surgical treatment outside of the country.

The findings build on previous work and offer further insight into high blood pressure and patient disability status after surgery for LSS. Although roughly half of the study participants were hypertensive, our results showed that surgical treatment for LSS is associated with reduced symptoms over the following 2 years regardless of blood pressure status. While we did not find an association between HBP and post-surgical pain and disability outcomes, larger studies are necessary to establish this relationship in the LSS patient population.

Chapter VI: Conclusions and Recommendations

The primary objective of this study was to determine the effects of HBP on post-operative disability for patients with LSS. Earlier evidence provided support for the association between HBP patients with LSS (Battie et al., 2012; Lotan et al., 2008; Uesugi et al., 2013), and the negative effects of cardiovascular comorbidity on the post-operative functional recovery after LSS-related surgery (Aalto et al., 2006). Given the high prevalence of HBP in the general population and earlier studies that reported an association between HBP and lower overall health in LSS patients, we examined the role of HBP in surgical patients with LSS. While both HBP and LSS are age-dependent conditions (Robitaille et al., 2012; Saban et al., 2007), previous research provided the over-arching foundation to identify which pre-existing comorbidities affect functional outcomes after surgical treatment for LSS (Aalto et al., 2006; Battie et al., 2012; Foulongue et al. 2012; Katz et al. 1999; Ucan & Ovayolu, 2010; Poljicanin et al., 2010; Uesugi et al., 2013; Lotan et al., 2008). With the increasing number of LSS-related surgeries (Aalto et al., 2006), the findings of this research are timely and contribute to existing knowledge that have implications for future study and clinical practice.

Surgical treatment for LSS is the most common low back procedure in patients aged 65 years and older (Aalto et al., 2006). In the United States alone, a total of 28,462 patients aged 18 and older who underwent either decompressive laminectomy or fusion between 2000 and 2009 (Lad et al., 2014). Additionally, in 2007, 135.5 patients per 100,000 Medicare beneficiaries received LSS-related surgery (Deyo et al., 2010). Through the use of Alberta Health data, this study offers a provincial perspective on a disease that is expected

to grow with the aging population because of its degenerative nature. Previous research has called for making informed decisions regarding patient comorbidity before undergoing this common surgical treatment (Battie et al., 2012; Deyo et al., 2010), and the current study has made contributions toward this effort.

HBP is a prevalent condition in the general population with a high prevalence of HBP in the elderly population (Robitaille et al., 2012). Because both HBP and surgery for LSS are common in older populations, hypertensive patients may experience more perioperative complications than those without HBP. Risk-adjusted analysis has shown that hypertensive patients aged 70 years or older are at increased risk of perioperative complications after lumbar spinal fusion surgery compared to younger age groups ($p=0.024$) (Kim et al., 2013). Other research by Browner et al. highlight perioperative complications in 474 hypertensive males who underwent non-cardiac surgery who had a 3.8 increased odds of death as compared to normotensive surgical patients (95% CI: 1.1, 13) (1992). Another consideration for perioperative complications is the use of general anesthesia during surgery as it has been shown to increase BP in patients with and without pre-existing HBP (Erstad & Barletta, 2000).

Although roughly half of the participants in the surgical cohort had HBP, the adjusted coefficient for HBP did not significantly affect surgical recovery for LSS. Given the early evidence of lower health status in HBP patients with LSS than normotensive patients and the high proportion of the study cohort with pre-existing HBP, it was unexpected that post-operative disability did not vary between the 2 BP groups. It is important to highlight that

even if the effect of HBP on post-operative disability was statistically significant, the size of the effect would have been very small. Three possible reasons may explain why our results did not show statistical significance. First, given the small number of 97 participants included in the study cohort, which had 6.6% power, it would be a challenge to demonstrate a statistically significant effect if one existed. Second, the current study used a spine-specific measure that assessed disability. The use of a generic measure would have been more susceptible to the effects of HBP because it evaluates overall health and is more responsive to lifestyle-related conditions. Third, is a selection bias, since survey participants were not randomly selected but rather selected based on an underlying condition (i.e. LSS). It is possible that participants selected for the Alberta LSS Study did not include patients whose HBP would affect post-operative disability.

Our analysis revealed that the study cohort experienced large gains in functional recovery and symptom reduction up to 2 years after surgery, which are consistent with the findings from related research (Weinstein et al., 2010; Chen & Spivak, 2003). After being diagnosed with LSS, conservative treatment is typically provided to manage the symptoms of LSS. When conservative management fails to relieve symptoms, patients should be considered for surgical intervention; however, patients may express reluctance due to uncertain surgery outcomes (Chen & Spivak, 2003). For patients concerned about undergoing LSS-related surgery, the current findings show that participants were likely to see improvements in post-operative disability status irrespective of BP status.

Recommendations for Research

The findings from this study revealed areas of further research that would benefit the understanding of post-operative disability outcomes within the LSS patient population. Research focused on perioperative factors may improve knowledge of what determines the prognosis of post-operative disability. The current literature for the prognostic factors of surgical outcome has primarily investigated pre-operative factors when patients undergo surgery for LSS; however, limited research has addressed how perioperative factors might predict post-operative outcome. Surgical and perioperative factors such as the duration of operation or blood loss during surgery could serve as important factors of post-operative disability status. Further investigation may provide a clearer clinical picture for the prognosis of LSS.

Extensions of the current research might evaluate the effect of long-term HBP (> 5 years) and symptom severity of HBP on surgical recovery for LSS patients. Measuring the pre-operative time that each participant is hypertensive may pose challenges for researchers due to the modifiable nature of HBP. Because HBP is modifiable through medications and changes in lifestyle, participants may become intermittently normotensive within the study timeframe, which was a possible scenario in the current study.

Further research may explore the time-related relationship between the onset of symptoms and the diagnosis of LSS, and the effect these have on the patient's post-operative disability status. Current research has not established whether patients seeking early treatment have better post-operative recovery outcomes, but there may be difficulty

when researchers differentiate between patients treated 'early' rather than 'later.' Before investigators can establish whether treatment was 'early' versus 'late,' the underlying challenge is assembling a cohort from the time of diagnosis until surgical treatment. Researchers should be cognizant of lead time bias when analyzing patients who sought early surgical treatment since their disability status may not be as worse compared to patients who sought surgery long after their diagnosis. This may involve further consideration for the length of time patients went undiagnosed and experienced symptoms characteristic of LSS.

Recommendations for Clinical Practice

The clinical implications of the findings from this work may help surgeons in screening patients for LSS-related surgery. Because the current results did not show that HBP affected post-operative disability, the physician and patient may agree to move forward with surgical treatment. It should be noted that the results of this study were based on participants with controlled HBP and may not apply to those with uncontrolled HBP.

A primary concern for patients is whether surgical treatment will alleviate the symptoms of LSS and the extent of functional ability once surgical wounds have healed. The current findings showed that surgical intervention had a large practical effect on symptom and functional recovery that was independent of BP status. Furthermore, patients going in to surgery with higher functional scores can expect to attain higher functional scores up to 2 years post-operatively. The clinical implication is that patients with the most severe symptoms of LSS may not be selected for surgery, which leaves the most vulnerable

patients without an effective means of treatment. Improving functional status through a directed pre-operative exercise program may result in better surgical outcomes as shown in a RCT with a similar patient population undergoing lumbar spine surgery. (Nielson et al., 2010). Among other considerations during the surgeon-patient consultation, our findings may influence the decision of whether the patient undergoes surgery.

Conclusion

While further investigation is warranted, the current findings support the notion that HBP does not negatively affect surgical disability after treatment for LSS. The current study identified other confounders that affect the post-operative disability status for the LSS patient population, which may offer a foundation for further research. The clinical significance of our findings will help provide additional guidance to make informed surgical decisions during physician-patient consultations.

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Appendix A: Alberta Lumbar Spinal Stenosis Study Survey Questionnaire (Select Pages)

Marital Status: ☐1 Married/common-law ☐2 Single/Widowed/Separated/Divorced

Who lives with you (check as many as apply)

☐1. Home alone
☐2. Husband or wife
☐3. Children/Siblings/Grandchildren/Friends
☐4. Non-related paid helper

Do you live with someone who can take care of you in the case that you need assistance?
☐1 Yes ☐0 No

What is your employment status?

☐1 Employed full time ☐4 Retired
☐2 Employed part time ☐5 Disability
☐3 Unemployed ☐6 Student

Does your back problem affect your employment status? ☐1 Yes ☐0 No

How long ago did the back and/or leg problems that you are currently experiencing begin?

Back pain: ☐1 Yes ☐0 No ☐-9 *Don't Know*
Which Month:_____ (eg. January)
Which Year:_____ (eg. 2001)

Leg pain: ☐1 Yes ☐0 No ☐-9 *Don't Know*
Which Month:_____ (eg. January)
Which Year:_____ (eg. 2001)

Walking speed *(Makan et al. Oxford Claudication Score)*

On the average, which statement best describes your walking over the past month?

☐1 I am able to walk at a normal speed
☐2 I walk slowly standing upright
☐3 I walk slowly bent forward
☐4 I have to stop and stand still when I walk
☐5 I have to stop and sit down when I walk
☐6 I cannot walk at all

Has surgery been offered to you as a treatment option for your current back problem?	Yes	No	
If yes, do you plan to have back surgery? OR *If surgery was already performed since your spine imaging on …, note date of surgery:* _____(month),_____(year).	Yes	No	Undecided

Have you had surgery on your low back <u>prior</u> to your recent imaging study last ___(mo)? ☐0 No ☐1 Yes

If yes, how many previous low back surgeries have you had? ____

Date: _____(mo)_____(yr) . . . . . Was this for a similar type of back problem? ☐0 No ☐1 Yes

_____(mo)_____(yr) . . . . . Was this for a similar type of back problem? ☐0 No ☐1 Yes

In the last month how would you describe: *(Swiss Spinal Stenosis Questionnaire symptom severity scale)*

1. The pain you have had on average including pain in your back, buttocks, and pain that goes down the legs?

☐0 None ☐1 Mild ☐2 Moderate ☐3 Severe ☐4 Very Severe ☐-9 *Don't Know*

2. How often have you had back, buttock, or leg pain?

☐1 < 1week ☐2 At least once a week ☐3 Every day for at least a few minutes ☐4 Every day for most of the day

☐5 Every minute of the day ☐-9 *Don't Know*

3. The pain in your back or buttocks?

☐0 None ☐1 Mild ☐2 Moderate ☐3 Severe ☐4 Very Severe ☐-9 *Don't Know*

4. The pain in your legs or feet?

☐0 None ☐1 Mild ☐2 Moderate ☐3 Severe ☐4 Very Severe ☐-9 *Don't Know*

5. Numbness or tingling in your legs or feet?

☐0 None ☐1 Mild ☐2 Moderate ☐3 Severe ☐4 Very Severe ☐-9 *Don't Know*

6. Weakness in your legs or feet?

☐0 None ☐1 Mild ☐2 Moderate ☐3 Severe ☐4 Very Severe ☐-9 *Don't Know*

7. Problems with your balance?

☐0 No, I've had no problems with balance

☐1 Yes, sometimes I feel my balance is off, or that I am not sure footed

☐2 Yes, often I feel my balance is off, or that I am not sure-footed ☐-9 *Don't Know*

In the last month on a typical day: *(Swiss Spinal Stenosis Questionnaire symptom function scale)*

8. How far have you been able to walk?

☐1 Over 2 miles ☐2 Over 2 blocks, but less than 2 miles ☐3 Over 50 ft., but less than 2 blocks ☐4 Less than 50 ft
☐-9 *Don't Know*

9. Have you taken walks outdoors or in malls for pleasure?

☐1 Yes comfortably ☐2 Yes, but sometimes with pain ☐3 Yes, but always with pain ☐4 No
☐-9 *Don't Know*

10. Have you been shopping for groceries or other items?

☐1 Yes, comfortably ☐2 Yes, but sometimes with pain ☐3 Yes, but always with pain ☐4 No
☐-9 *Don't Know*

11. Have you walked around the different rooms in your house or apartment?

☐1 Yes comfortably ☐2 Yes, but sometimes with pain ☐3 Yes, but always with pain ☐4 No
☐-9 *Don't Know*

12. Have you walked from your bedroom to the bathroom?

☐1 Yes, comfortably ☐2 Yes, but sometimes with pain ☐3 Yes, but always with pain ☐4 No
☐-9 *Don't Know*

Oswestry Disability Questionnaire

Now I am going to go through a 9-item questionnaire designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please let me know which response best applies to you or which most clearly describes your problem today.

Section 1 - Pain Intensity

☐1 I have no pain at the moment
☐2 The pain is very mild at the moment
☐3 The pain is moderate at the moment
☐4 The pain is fairly severe at the moment
☐5 The pain is very severe at the moment
☐6 The pain is the worst imaginable at the moment

Section 2 - Personal Care (washing, dressing etc)

☐1 I can look after myself normally without causing extra pain
☐2 I can look after myself normally but it causes extra pain
☐3 It is painful to look after myself and I am slow and careful
☐4 I need some help but can manage most of my personal care
☐5 I need help every day in most aspects of self care
☐6 I do not get dressed, wash with difficulty and stay in bed

Section 3 - Lifting

☐1 I can lift heavy weights without extra pain
☐2 I can lift heavy weights but it gives me extra pain
☐3 Pain prevents me lifting heavy weights off the floor but I can manage if they are conveniently placed eg. on a table
☐4 Pain prevents me lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
☐5 I can only lift very light weights

Section 4 – Walking*

☐1 Pain does not prevent me walking any distance
☐2 Pain prevents me from walking more than 2 kilometers
☐3 Pain prevents me from walking more than 1 kilometer
☐4 Pain prevents me from walking more than 500 meters
☐5 I can only walk using a stick or crutches
☐6 I am in bed most of the time

Section 5 - Sitting

☐1 I can sit in any chair as long as I like
☐2 I can only sit in my favorite chair as long as I like
☐3 Pain prevents me sitting more than one hour
☐4 Pain prevents me from sitting more than 30 minutes
☐5 Pain prevents me from sitting more than 10 minutes
☐6 Pain prevents me from sitting at all

Section 6 - Standing

☐1 I can stand as long as I want without extra pain
☐2 I can stand as long as I want but it gives me extra pain
☐3 Pain prevents me from standing for more than 1 hour
☐4 Pain prevents me from standing for more than 30 minutes
☐5 Pain prevents me from standing for more than 10 minutes
☐6 Pain prevents me from standing at all

Section 7 - Sleeping

☐1 My sleep is never disturbed by pain
☐2 My sleep is occasionally disturbed by pain
☐3 Because of pain I have less than 6 hours sleep
☐4 Because of pain I have less than 4 hours sleep
☐5 Because of pain I have less than 2 hours sleep
☐6 Pain prevents me from sleeping at all

Section 8 - Social Life

☐1 My social life is normal and gives me no extra pain
☐2 My social life is normal but increases the degree of pain
☐3 Pain has no significant effect on my social life apart from limiting my more energetic interests e.g. sport
☐4 Pain has restricted my social life and I do not go out as often
☐5 Pain has restricted my social life to my home
☐6 I have no social life because of pain

Section 9 - Travelling

☐1 I can travel anywhere without pain
☐2 I can travel anywhere but it gives me extra pain
☐3 Pain is bad but I manage journeys over two hours
☐4 Pain restricts me to journeys of less than one hour
☐5 Pain restricts me to short necessary journeys under 30 minutes
☐6 Pain prevents me from travelling except to receive treatment

The next questions deal with how you are feeling. This will give us information on how people with back problems such as yours are coping overall. *(CES-D depression scale - Circle one number on each line.)*

During the past 1 week:	Rarely or none of the time (less than a day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of the time (3-4 days)	Most or all of the time (5-7 days)	Don't Know
1. I was bothered by things that usually don't bother me	0	1	2	3	-9
2. I did not feel like eating: my appetite was poor.	0	1	2	3	-9
3. I felt that I could not shake off the blues even with help from my family or friends.	0	1	2	3	-9
4. I felt that I was just as good as other people.	0	1	2	3	-9
5. I had trouble keeping my mind on what I was doing.	0	1	2	3	-9
6. I felt depressed.	0	1	2	3	-9
7. I felt that everything I did was an effort.	0	1	2	3	-9
8. I felt hopeful about the future.	0	1	2	3	-9
9. I though my life had been a failure.	0	1	2	3	-9
10. I felt fearful.	0	1	2	3	-9
11. My sleep was restless.	0	1	2	3	-9
12. I was happy.	0	1	2	3	-9
13. I talked less than usual.	0	1	2	3	-9
14. I felt lonely	0	1	2	3	-9
15. People were unfriendly	0	1	2	3	-9
16. I enjoyed life.	0	1	2	3	-9
17. I had crying spells	0	1	2	3	-9
18. I felt sad.	0	1	2	3	-9
19. I felt that people dislike me.	0	1	2	3	-9
20. I could not get "going".	0	1	2	3	-9

Now I would like to ask you a few questions about your overall health.

Please indicate if you currently have any of the following conditions. ☐ No Conditions		**Are you currently receiving treatment for it.**	**Over the past week how much has the condition limited you when performing your regular activities** *Circle one number on each line.*				
Tick if Present		**Yes**	None	Mild	Moderate	Severe	Don't know
☐	Asthma	☐	0	1	2	3	-9
☐	Chronic bronchitis or emphysema	☐	0	1	2	3	-9
☐	Arthritis or rheumatism	☐	0	1	2	3	-9
☐	Back problems, excluding arthritis	☐	0	1	2	3	-9
☐	High blood pressure	☐	0	1	2	3	-9
☐	Heart Disease	☐	0	1	2	3	-9
☐	Diabetes	☐	0	1	2	3	-9
☐	Cancer	☐	0	1	2	3	-9
☐	Effects of a stroke	☐	0	1	2	3	-9
☐	Migraine headaches	☐	0	1	2	3	-9
☐	Alzheimer's disease or any other dementia	☐	0	1	2	3	-9
☐	Urinary incontinence	☐	0	1	2	3	-9
☐	A bowel disorder such as Crohn's disease or colitis	☐	0	1	2	3	-9
☐	A thyroid condition	☐	0	1	2	3	-9
☐	Any other long-term condition that has been diagnosed by a health professional:	☐					
1.	_____	☐	0	1	2	3	-9
2.	_____	☐	0	1	2	3	-9
3.	_____	☐	0	1	2	3	-9
4.	_____	☐	0	1	2	3	-9
5.	_____	☐	0	1	2	3	-9
6.	_____	☐	0	1	2	3	-9
7.	_____	☐	0	1	2	3	-9
8.	_____	☐	0	1	2	3	-9
9.	_____	☐	0	1	2	3	-9
10.	_____	☐	0	1	2	3	-9

Appendix B: Relevant Surgical Procedure and Diagnostic Codes

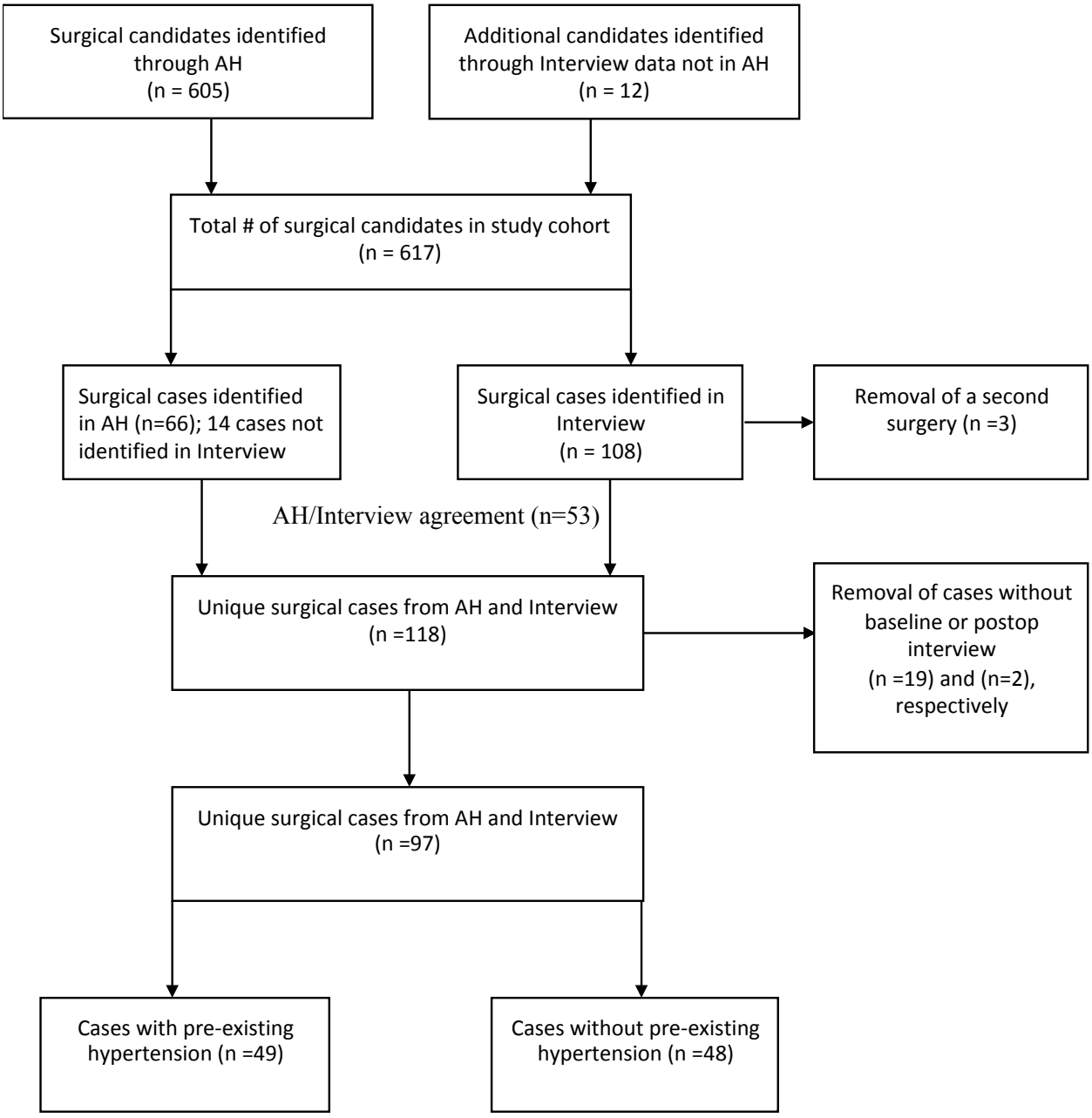
Procedure Codes to Identify LSS-related Surgery*
1.SC.74 = spinal vertebrae, fixation
1.SC.75 = spinal vertebrae, fusion
1.SC.89 = excision total, spinal vertebrae
1.SE.53 = implantation of internal device, intervertebral disc
1.SC.80 = repair, spinal vertebrae
1.SE.89 = excision total, intervertebral disc
1.SE.87 = excision, partial, intervertebral disc
ICD9-CM Diagnostic Codes to Identify LSS
724.0 = spinal stenosis, other than cervical
724.00 = multiple sites
ICD10-CM Diagnostic Codes to Identify LSS
M4800 = Spinal stenosis, multiple sites in spine
M4805 = spinal stenosis, thoracolumbar region
M4806 = spinal stenosis, lumbar region
M4807 = spinal stenosis, lumbosacral region

*Canadian Classification of Health Interventions Volume 3

Appendix C: Assumptions of Multiple Linear Regression

- The underlying assumptions of statistical tests were performed on all data included in each of the three regression models. The assumptions for MLR are as follows: a linear relationship with the outcome variable; homoscedasticity; normally distributed residuals; absence of collinearity and independent residuals.
- Testing the linearity assumption involves the plotting of each continuous variable included in the model against the outcome variable. Each continuous variable must have a linear relationship with the outcome variable to meet the linearity assumption.
- The variance of the residuals refers to homoscedasticity, which is tested by plotting standardized predicted values by standardized residuals. A scatterplot with data points randomly distributed along the x and y-axis satisfies the homoscedasticity assumption.
- The normality assumption was tested using a normal probability plot of the standardized residuals. A plot with a straight line meets the normality assumption. In addition, a bell-shaped histogram of the standardized residuals also meets the normality assumption.
- Collinearity refers to a strong linear relationship between two prognostic factors. The variance inflation factor (VIF) assesses this assumption during MLR analysis. VIF values less than 5.0 suggests it is unlikely that collinearity is present in the MLR model.
- The independent residuals assumption was assessed during analysis using the Durbin-Watson statistic. Values of the Durbin-Watson statistic greater than 1.0 meet the independent residuals assumption.

Appendix D: Surgical Flow Diagram



Appendix E: Post-operative Complications and Groupings

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ICD9/10-CM Code	Diagnosis Description	Complication Type
353	cervical root lesions not elsewhere classified	Spine complication
721	spondylolis and allied disorders	Spine complication
721.3	lumbosacral spondylosis without myelopathy	Spine complication
722.1	displacement of thoracic or lumbar intervertebral disc without myelopathy	Spine complication
723	other disorders of cervical region	Spine complication
738.4	acquired spondylolisthesis	Spine complication
739	other acquired deformity of the back or spine	Spine complication
805	fracture of vertebral column without mention of spinal cord injury	Spine complication
845	sprains and strains of other specified sites of knee and leg	Spine complication
846	strains and sprains of the sacroilliac region	Spine complication
847	sprains and strains of other and unspecified parts of the back	Spine complication
847.2	sprain of lumbar	Spine complication
996	unspecified mechanical complication of internal orthopedic device, implant, and graft	Spine complication
996.7	other complications due to internal prosthetic deivce, implant and graft	Spine complication
N814	displacement of thoracic or lumbar intervertebral disc without myelopathy	Spine complication
9	collitis septic	Skin/infection complication
38.9	other septicemia	Skin/infection complication
462	acute pharyngitis	Skin/infection complication
465	acute upper respiratory infections of multiple or unspecified sites	Skin/infection complication
616	vaginitis and vulvovaginitis	Skin/infection complication
686	other local infections of skin and subcutaneous tissue	Skin/infection complication
782	symptoms involving skin and other integumentary tissue	Skin/infection complication
906	late effects of injuries to skin and subcutaneous tissue	Skin/infection complication
998.5	postoperative infection not elsewhere classfied	Skin/infection complication
N72	inflammatory disease of the cervix/uteri	Skin/infection complication
344	other paralytic syndromes	Other musculoskeletal complication
715	osteoarthritis and allied disorders	Other musculoskeletal complication
719.4	pain in joint	Other musculoskeletal complication
727	other disorders of the synovium tendom and bursa	Other musculoskeletal complication
729	other disorders of soft tissues	Other musculoskeletal complication
730	pain in limb	Other musculoskeletal complication
733	other disorders of bone and joint cartilage	Other musculoskeletal complication
781	symptoms involving nervous and musculoskeletal systems	Other musculoskeletal complication
808	fracture of pelvis	Other musculoskeletal complication
M213	other disorders of bone and joint cartilage	Other musculoskeletal complication
363	other retinal disorders	Eye-related complication
365	glaucoma	Eye-related complication
372	disorders of conjunctiva	Eye-related complication
555	regional enteritis	Digestive system complication
564	irritable bowel syndrome	Digestive system complication
595	inflammation of the urinary bladder	Digestive system complication
596	cystitis unspecified	Digestive system complication
787	symptoms involving digestive system	Digestive system complication
K519	ulcerlative collitis	Digestive system complication
K580	irritable bowel syndome with diarrhea	Digestive system complication
R33	retention of urine	Digestive system complication
300	anxiety states	Depressive/anxiety complication
308	acute reaction to stress	Depressive/anxiety complication
311	depressive disorder	Depressive/anxiety complication
286	anemia unspecified	Cardiovascular complication
410	acute myocardial infarction	Cardiovascular complication
412	old myocardial infarction	Cardiovascular complication
413	angina pectoris	Cardiovascular complication
414	coronary atherosclerosis	Cardiovascular complication
427	atrial fibrillation and flutter	Cardiovascular complication
428	other specified cardiac dysrhythmias	Cardiovascular complication
452	portal vein thrombosis	Cardiovascular complication
453	other venous embolism and thrombosis	Cardiovascular complication
785	symptoms involving cardiovascular system	Cardiovascular complication
785.9	other symptoms involving cardiovascular system	Cardiovascular complication
786.5	chest pain	Cardiovascular complication
790	ascites	Cardiovascular complication
D509	iron deficiency anemia	Cardiovascular complication
I2510	atherosclerotic heart disease of native coronary artery without angina pectoris	Cardiovascular complication
I480	paroxysmal atrial fibrillation	Cardiovascular complication

Appendix F: Univariate Analysis of Oswestry Disability Index

Variable n=95	Unstandardized Coefficients B	Stanadard Error	Standardized Coefficients	P-Value	95.0% Confidence Interval for B	
					Lower Bound	Upper Bound
Pre-existing hypertension	1.386	3.576	0.040	0.699	-5.716	8.488
Age	-0.174	0.138	-0.130	0.210	-0.448	0.100
Gender, female (male reference)	6.591	3.518	0.191	0.064	-0.395	13.578
Education:						
Completed highschool vs. not complet	-8.395	5.766	-0.149	0.149	-19.845	3.055
Living Situation:						
Living with another person/married vs.						
living alone/unmarried	-3.395	5.195	-0.068	0.515	-13.711	6.922
Follow-up Time:						
≥ 6 Months vs. reference	-8.725	4.079	-0.217	0.035	-16.824	-0.626
< 6 Months (reference)	n/a					
Follow-up Time (continuous)	-0.012	0.012	-0.107	0.301	-0.036	0.011
Comorbidity:						
Alzheimers vs. no comorbidity	26.669	17.429	0.158	0.129	-7.950	61.289
Anemia vs. no comorbidity	-16.012	17.571	-0.095	0.365	-50.915	18.891
Arthritis vs. no comorbidity	1.855	6.577	0.031	0.779	-11.232	14.942
Bowel Disorder vs. no comorbidity	2.255	6.153	0.038	0.715	-9.967	14.477
Cancer vs. no comorbidity	10.251	5.323	0.198	0.057	-0.322	20.825
Cerebrovascular Disease vs. no comorbidity	0.010	10.405	0.000	0.999	-20.693	20.713
Depression vs. no comorbidity	6.101	4.006	0.158	0.131	-1.856	14.057
Diabetes vs. no comorbidity	-4.269	4.929	-0.090	0.389	-14.061	5.523
Effects of Stroke vs. no comorbidity	5.387	12.537	0.045	0.668	-19.516	30.290
Heart Disease vs. no comorbidity	0.427	3.967	0.011	0.915	-7.452	8.305
Incontinence vs. no comorbidity	8.800	4.117	0.219	0.035	0.622	16.979
Kidney Disease vs. no comorbidity	-9.273	17.625	-0.055	0.600	-44.282	25.736
Obesity vs. no comorbidity	0.288	6.246	0.005	0.963	-12.140	12.715
Peripheral Vascular Disease vs. no comorbidity	16.519	12.531	0.145	0.191	-8.414	41.451
Respiratory Disorder vs. no comorbidit	8.187	6.388	0.132	0.203	-4.499	20.872
Thyroid Disorder vs. no comorbidity	5.946	5.395	0.115	0.273	-4.770	16.662
Stomach Ulcer vs. no comorbidity	-9.375	12.511	-0.078	0.456	-34.227	15.477
Vision Disturbance vs. no comorbidity	34.312	17.388	0.214	0.052	-0.285	68.908
Migraine vs. no comorbidity	2.095	5.086	0.043	0.681	-8.008	12.198
Number of comorbidities	7.294	2.868	0.258	0.013	1.598	12.991
CES Depression Scale:						
Depressed (score of 19 or higher)	12.071	3.355	0.350	0.001	5.409	18.733
Medications:						
Analgesics vs. no medication	-2.434	5.826	-0.043	0.677	-14.003	9.135
Antidepressants vs. no medication	8.607	4.021	0.217	0.035	0.622	16.591
Any medication taken for back pain vs. no medication	0.986	8.014	0.013	0.902	-14.927	16.900
Epidural Steroid Injections (EPIs) vs. no medication	5.024	6.089	0.085	0.411	-7.067	17.115
Muscle Relaxants vs. no medication	2.795	3.914	0.074	0.477	-4.978	10.568
Narcotics vs. no medication	1.604	3.580	0.046	0.655	-5.505	8.714
Sedatives vs. no medication	5.328	3.976	0.138	0.183	-2.567	13.223
Medication Sum	2.152	1.308	0.168	0.103	-0.445	4.748

Appendix G: Univariate Analysis for Swiss Spinal Stenosis Symptom Severity Scale

Variable n=94	Unstandardized Coefficients B	Standard Error	Standardized Coefficients	P-Value	95.0% Confidence Interval for B	
					Lower Bound	Upper Bound
Pre-existing hypertension	0.019	0.166	0.012	0.113	-0.311	0.349
Age	-0.008	0.006	-0.132	0.204	-0.021	0.005
Gender, female	0.184	0.165	0.115	0.270	-0.145	0.512
Married vs. unmarried	-0.402	0.179	-0.228	0.027	-0.757	-0.047
Education:						
Completed highschool vs. not completed	-0.476	0.265	-0.184	0.075	-1.002	0.05
Living Situation:						
Living with another person/married vs. living alone/unmarried	-0.281	0.239	-0.122	0.243	-0.755	0.194
Follow-up Time:						
≥ 6 Months vs. reference	-0.253	0.191	-0.137	0.189	-0.633	0.127
< 6 Months (reference)	n/a					
Follow-up Time (continuous)	0.000	0.001	-0.067	0.521	-0.001	0.001
Comorbidity:						
Alzheimers vs. no comorbidity	1.617	0.792	0.211	0.044	0.045	3.190
Anemia vs. no comorbidity	-0.982	0.803	-0.128	0.225	-2.578	0.613
Arthritis vs. no comorbidity	-0.010	0.304	-0.004	0.974	-0.615	0.595
Bowel Disorder vs. no comorbidity	-0.067	0.298	-0.024	0.824	-0.658	0.525
Cancer vs. no comorbidity	0.526	0.243	0.222	0.033	0.043	1.009
Cerebrovascular Disease vs. no comorbidity	0.324	0.479	0.076	0.500	-0.629	1.277
Depression vs. no comorbidity	0.209	0.185	0.118	0.261	-0.158	0.577
Diabetes vs. no comorbidity	-0.012	0.227	-0.005	0.960	-0.463	0.440
Effects of Stroke vs. no comorbidity	0.102	0.576	0.019	0.860	-1.042	1.246
Heart Disease vs. no comorbidity	0.046	0.186	0.026	0.806	-0.323	0.415
Incontinence vs. no comorbidity	0.154	0.193	0.084	0.428	-0.230	0.538
Kidney Disease vs. no comorbidity	0.318	0.809	0.041	0.696	-1.290	1.925
Obesity vs. no comorbidity	0.244	0.287	0.095	0.398	-0.327	0.815
Peripheral Vascular Disease vs. no comorbidity	0.833	0.577	0.159	0.153	-0.315	1.981
Respiratory Disorder vs. no comorbidity	0.442	0.294	0.155	0.137	-0.143	1.026
Thyroid Disorder vs. no comorbidity	0.197	0.248	0.083	0.430	-0.297	0.691
Stomach Ulcer vs. no comorbidity	-0.409	0.574	-0.075	0.478	-1.550	0.732
Vision Disturbance vs. no comorbidity	0.461	0.820	0.063	0.575	-1.170	2.092
Migraine vs. no comorbidity	0.106	0.233	0.048	0.652	-0.358	0.570
Sum of comorbidities	0.250	0.134	0.193	0.065	-0.016	0.516
CES Depression Scale:						
Depressed (score of 19 or higher)	0.262	0.164	0.164	0.113	-0.064	0.588
Medications:						
Analgesics vs. no medication	-0.300	0.268	-0.116	0.265	-0.832	0.231
Antidepressants vs. no medication	0.248	0.189	0.136	0.192	-0.127	0.623
Any medication taken for back pain vs. no medication	0.381	0.368	0.107	0.304	-0.350	1.111
Epidural Steroid Injections (EPIs) vs. no medication	0.152	0.297	0.053	0.610	-0.438	0.743
Muscle Relaxants vs. no medication	0.090	0.181	0.052	0.622	-0.271	0.450
Narcotics vs. no medication	-0.055	0.166	-0.034	0.743	-0.385	0.275
Sedatives vs. no medication	0.262	0.184	0.147	0.157	-0.103	0.627
Medication Sum	0.058	0.061	0.099	0.341	-0.063	0.179

Appendix H: Univariate Analysis for Swiss Spinal Stenosis Physical Function Scale

Variable n=92	Unstandardized Coefficients B	Standard Error	Standardized Coefficients	P-Value	95.0% Confidence Interval for B	
					Lower Bound	Upper Bound
Pre-existing hypertension	0.153	0.144	0.111	0.292	-0.134	0.439
Age	-0.003	0.006	-0.048	0.652	-0.014	0.009
Gender, female	0.020	0.145	0.015	0.891	-0.269	0.309
Education:						
Completed highschool vs. not completed	-0.327	0.242	-0.141	0.180	-0.807	0.153
Living Situation:						
Living with another person/married vs. living alone/unmarried	0.027	0.208	0.014	0.897	-0.387	0.441
Follow-up Time:						
≥ 6 Months vs. reference	-0.241	-0.152	-1.458	0.148	-0.570	0.088
< 6 Months (reference)	n/a					
Follow-up Time (continuous)	0.000	0.000	-0.088	0.404	-0.001	0.001
Comorbidity:						
Alzheimers vs. no comorbidity	1.183	0.688	0.180	0.089	-0.185	2.550
Anemia vs. no comorbidity	0.778	0.694	0.119	0.266	-0.602	2.158
Arthritis vs. no comorbidity	0.012	0.248	0.005	0.962	-0.482	0.505
Bowel Disorder vs. no comorbidity	0.200	0.257	0.083	0.439	-0.311	0.710
Cancer vs. no comorbidity	0.277	0.214	0.137	0.198	-0.147	0.702
Cerebrovascular Disease vs. no comorbidity	0.427	0.388	0.123	0.275	-0.346	1.200
Depression vs. no comorbidity	0.081	0.162	0.054	0.615	-0.240	0.402
Diabetes vs. no comorbidity	-0.100	0.202	-0.053	0.623	-0.501	0.302
Effects of Stroke vs. no comorbidity	-0.440	0.495	-0.094	0.376	-1.424	0.544
Heart Disease vs. no comorbidity	-0.075	0.161	-0.049	0.641	-0.395	0.244
Incontinence vs. no comorbidity	0.231	0.166	0.146	0.169	-0.100	0.561
Kidney Disease vs. no comorbidity	-0.435	0.698	-0.066	0.534	-1.822	0.951
Obesity vs. no comorbidity	-0.013	0.235	-0.006	0.956	-0.481	0.455
Peripheral Vascular Disease vs. no comorbidity	-0.092	0.476	-0.022	0.848	-1.039	0.856
Respiratory Disorder vs. no comorbidity	0.115	0.257	0.047	0.655	-0.396	0.626
Stomach Ulcer vs. no comorbidity	0.173	0.497	0.037	0.728	-0.814	1.161
Thyroid Disorder vs. no comorbidity	0.296	0.213	0.147	0.168	-0.127	0.720
Vision Disturbance vs. no comorbidity	1.226	0.655	0.207	0.065	-0.077	2.529
Migraine vs. no comorbidity	0.184	0.201	0.097	0.364	-0.216	0.584
Sum of comorbidities	0.164	0.118	0.146	0.169	-0.071	0.398
CES Depression Scale:						
Depressed (score of 19 or higher)	0.164	0.144	0.119	0.259	-0.122	0.450
Medications:						
Analgesics vs. no medication	-0.302	0.242	-0.130	0.215	-0.783	0.179
Antidepressants vs. no medication	0.077	0.165	0.049	0.640	-0.250	0.405
Any medication taken for back pain vs. no medication	-0.064	0.356	-0.019	0.857	-0.771	0.642
Epidural Steroid Injections (EPIs) vs. no medication	-0.261	0.256	-0.107	0.310	-0.770	0.247
Muscle Relaxants vs. no medication	-0.081	0.159	-0.053	0.613	-0.397	0.235
Narcotics vs. no medication	-0.058	0.145	-0.042	0.689	-0.346	0.230
Sedatives vs. no medication	0.096	0.161	0.063	0.551	-0.223	0.416
Medication Sum	-0.027	0.055	-0.051	0.627	-0.135	0.082

Appendix I: Univariate and Multiple Linear Regression for Post-operative Oswestry Disability Index

Variables	Univariate Analysis		Multivariable Analysis[a]	
	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value
(Constant)	N/A		19.29 (-3.74, 42.31)	0.099
Age	-0.17 (-0.45, 0.10)	0.210	-0.17 (-0.45, 0.11)	0.223
Gender (female)	6.59 (-0.40, 13.58)	0.064	5.10 (-1.21, 11.41)	0.112
Pre-existing hypertension	1.39 (-5.72, 8.49)	0.699	1.32 (-5.64, 8.28)	0.706
Follow-up time (< 6 months)	-8.73 (-16.82, -0.63)	0.035	-9.63 (-16.84, -2.43)	0.009
Pre-operative ODI[b]	0.50 (0.31, 0.69)	<0.001	0.38 (0.16, 0.60)	0.001
Number of comorbidities	2.29 (-0.11, 4.68)	0.061	1.06 (-1.35, 3.47)	0.382
CES-D[c]	12.07 (5.41, 18.73)	0.001	4.43 (-2.80, 11.65)	0.227

[a]Adjusted R^2=0.283

[b]Oswestry Disability Index

[c]Centre for Epidemiologic Studies Depression scale (Dichotomous, score cut-off 19+)

Appendix J: Multiple Linear Analyses of the Final Model and Change Model for the Oswestry Disability Index

Variables	Current Model[a]		Change Model[b]	
	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value
(Constant)	19.29 (-3.74, 42.31)	0.099	13.47 (-9.68, 36.62)	0.250
Age	-0.17 (-0.45, 0.11)	0.223	0.10 (-0.22, 0.42)	0.539
Gender (female)	5.10 (-1.21, 11.41)	0.112	-2.59 (-9.86, 4.68)	0.481
Pre-existing hypertension	1.32 (-5.64, 8.28)	0.706	-3.40 (-11.45, 4.65)	0.403
Follow-up time (<6 months)	-9.63 (-16.84, -2.43)	0.009	11.46 (3.11, 19.81)	0.008
Pre-operative ODI[c] score	0.38 (0.16, 0.60)	0.001	N/A	N/A
Number of comorbidities	1.06 (-1.35, 3.47)	0.382	0.77 (-1.93, 3.47)	0.573
CES-D[d]	4.43 (-2.80, 11.65)	0.227	5.02 (-2.44, 12.47)	0.184

[a] Adjusted R^2= 0.283

[b] Adjusted R^2= 0.031; Change refers to calculated difference between pre-operative and post-operative ODI score

[c] Oswestry Disability Index

[d] Centre for Epidemiologic Studies Depression scale
(Dichotomous, score cut-off 19+)

Appendix K: Univariate and Multiple Linear Regression for Post-operative Swiss Spinal Stenosis Scales

Variables	Swiss Spinal Stenosis Symptom Severity				Swiss Spinal Stenosis Physical Function			
	Univariate Analysis		Multivariable Analysis[a]		Univariate Analysis		Multivariable Analysis[b]	
	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value	Coefficient (95% CI)	P-Value
(Constant)	N/A		1.73 (0.61, 2.85)	0.003	N/A		1.67 (0.63, 2.71)	0.002
Age	-0.01 (-0.02, 0.01)	0.132	-0.01 (-0.03, 0.00)	0.060	0.00 (-0.01, 0.01)	0.652	-0.01 (-0.02, 0.01)	0.280
Gender (female)	0.18 (-0.15, 0.51)	0.115	0.22 (-0.11, 0.54)	0.191	0.02 (-0.27, 0.31)	0.891	-0.01 (-0.30, 0.28)	0.966
Pre-existing hypertension	0.02 (-0.31, 0.35)	0.113	0.03 (-0.33, 0.39)	0.886	0.15 (-0.13, 0.44)	0.292	0.17 (-0.15, 0.49)	0.302
Follow-up time (< 6months)	-0.25 (-0.63, 0.13)	0.189	-0.27 (-0.64, 0.11)	0.160	-0.24 (-0.57, 0.09)	0.148	-0.26 (-0.58, 0.07)	0.121
Pre-operative score	0.31 (0.05, 0.57)	0.018	0.25 (-0.02, 0.52)	0.067	0.01 (0.00, 0.02)	0.004	0.01 (0.00, 0.02)	0.013
Number of comorbidities	0.10 (-0.02, 0.21)	0.089	0.10 (-0.03, 0.22)	0.125	0.08 (-0.02, 0.18)	0.099	0.04 (-0.07, 0.15)	0.468
CES-D[c]	0.26 (-0.06, 0.59)	0.113	0.06 (-0.29, 0.41)	0.723	0.16 (-0.12, 0.45)	0.259	-0.13 (-0.47, 0.20)	0.438

[a] Adjusted R^2=0.080

[b] Adjusted R^2=0.074

[c] Centre for Epidemiologic Studies Depression scale