A Retrospective Analysis of Surgical, Patient, and Clinical Characteristics Associated with Length of Stay Following Lumbar Spine Surgery

by

Madison T. Stevens

Submitted in partial fulfilment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
June 2020

Table of Contents

List of Tables

List of Figures

Abstract

Background: Elective spine surgeries utilize significant hospital resources. Postoperative hospital length of stay (LOS) requires substantial nursing, nutritional, social, administrative, and overhead resources, thus contributing greatly to the costs of institutional care. Previous studies have identified several pre-, intra-, and post-operative factors associated with increased LOS following elective spine surgery; however, findings are not consistent between studies, and research has not been done in a Nova Scotian setting.

Objectives: **1)** To describe the distribution of the demographic, clinical, operative, and postoperative characteristics among patients undergoing elective lumbar spine surgery for single- and two-level degenerative conditions at a Nova Scotian quaternary care institution between October 2014 to October 2016. **2)** To describe how the demographic, clinical, operative, and postoperative characteristics are independently associated with LOS among the study population.

Methods: We conducted a retrospective cohort study using data collected at the Halifax Infirmary. The sample included consecutive patients (> 18 years of age) who underwent single- or two-level elective lumbar spine surgery for degenerative conditions between October 2014 to October 2016 at a single institution by one of two orthopedic spine surgeons. Potentially eligible patients were identified using International Classification of Diseases ninth revision codes. We reviewed patients' electronic medical charts and extracted information on demographic, clinical, and operative characteristics that we identified in studies from a systematic literature search. We collected and considered the following factors for inclusion in the statistical model: preoperative factors (sex, age, BMI, revision surgery, American Society of Anaesthesiology class, Charlson comorbidity index, hemoglobin level, narcotic-, antidepressant-, and neuroleptic-use, initial diagnosis, workers' compensation claim), operative factors (analgesics, transfusion, blood loss, surgical case time, surgery performed, complications, operating surgeon), and postoperative factors (hemoglobin level and transfusion). The outcome of interest was LOS, calculated as the number of days from the date of surgery to the date of discharge. We used descriptive statistics to summarize the data. We used multiple quasi-Poisson regression to describe the characteristics independently associated with LOS. We stratified by surgery group when feasible to explore heterogeneity within the study population.

Results: A total of 473 patients met inclusion criteria. The average age of patients was 59.6 years (95% confidence interval: [58.3, 61]). The median LOS was 3.0 days (Interquartile range (IQR) = 1-4) for the entire population, 4.0 days (IQR = 3-6) for 1-level transforaminal lumbar interbody fusion (TLIF) patients, 0 days (IQR = 0-1) for discectomy patients, and 2.0 days (IQR = 1-4) for laminectomy patients. Factors that were statistically significantly associated with LOS in adjusted analyses were age, BMI, preoperative antidepressant use, surgery group, long-acting intraoperative analgesics, operating surgeon, and postoperative blood transfusion. Stratified multivariable analysis showed effect modification by surgery group. Surgery group had the strongest association with LOS (RR > 3), followed by postoperative blood transfusion (RR > 1.5), intraoperative analgesics (RR < 1.5), and intraoperative complications (RR < 1.5).

Conclusions: LOS following elective lumbar spine surgery for degenerative conditions is associated with several patient, clinical, and surgical factors and is highly dependent on the type of surgical procedure performed. These findings provide preliminary evidence for future research to develop and test a predictive model for LOS and may contribute to quality improvement. The results also provide evidence for future research to focus on more homogenous populations, and include prospective, confirmatory studies.

List of Abbreviations Used

LBP	low back pain
LOS	length of stay
WCB	Workers' Compensation Board
BMI	body mass index
ASA	American Society of Anesthesiologists
CSORN	Canadian Spine Outcomes and Research Network
TLIF	transforaminal lumbar interbody fusion
ALIF	anterior lumbar interbody fusion
PLIF	posterior lumbar interbody fusion
VIF	variance inflation factor
US	United States
CI	confidence interval
IQR	interquartile range
RR	risk ratio

Acknowledgements

I would first like to acknowledge and express my deepest gratitude to my brilliant supervisors, Dr. Jill Hayden and Dr. Andrew Glennie. Your unwavering support, feedback, and mentorship have been instrumental throughout this process. I would also like to recognize and thank my outstanding committee members, Dr. Cynthia Dunning and Dr. Samuel Stewart, for their contribution and support. My heartfelt appreciation also extends to the Orthopedic Spine division at the Halifax Infirmary, who I have had the pleasure of working with for the past several years. My experience working in orthopedic spine research has significantly influenced the trajectory of my career. Lastly, I would like to thank my cherished friends and family for their love and support, as well as the those who generously provided financial support, including the Government of Nova Scotia, the Canadian Institute of Health Research, and the late and honourable Dr. Reginald Yabsley.

Chapter 1: Introduction

Low back pain (LBP) is a leading cause of disability and poses a significant burden to both individuals and ultimately society (1,2). The lifetime prevalence of LBP is estimated to be as high as 84% (3,4). Common degenerative conditions affecting the lumbar spine, presenting with LBP, include spondylolisthesis, spinal stenosis, disc herniation, and degenerative disc disease. The global annual incidence of degenerative lumbar spine conditions (with LBP) is estimated to be 3.63% (1).

Lumbar spine surgery is often used to treat chronic spine pathologies (5,6). Common surgical procedures include discectomies, laminectomies, and instrumented fusions. The rates of both laminectomy and fusion procedures have been rising internationally over the past two decades (7,8). Not only are the increasing rates noteworthy, but the high costs and significant resource consumption associated with spinal surgery places significant strain on systems with already limited resources. These trends make the study of postoperative outcomes imperative, including complications, readmissions, patient reported outcomes, and length of stay (LOS).

LOS following lumbar spine surgery is an outcome that is useful for hospital administrators to consider. It allows for the evaluation of care delivery, resource use, and hospital efficiency (9). Extended LOS may increase the risk of hospital acquired infections, lead to higher hospital costs, and may be suggestive of poor-care coordination (10–12). Identifying potentially modifiable and non-modifiable factors that are associated with a longer LOS is an important first step. Within the last decade efforts have been made to identify prognostic factors associated with LOS (particularly in the United States (US) population); however, findings are inconsistent and have not been investigated in the Nova Scotian setting. Importantly, postoperative care varies by hospital and geographic region, with differences in patient characteristics and individual and institutional practice (6). This gap leads to the primary objective of the proposed research, which is to describe the factors associated with LOS after elective lumbar spine surgery in a Nova Scotian population.

This thesis document is comprised of six distinct chapters:

- Chapter 1 provides an introduction to the topic in order to contextualize the research and situate the reader prior to delving into background information and previous literature.
- Chapter 2 includes background information on various spine pathologies and surgical procedures, justifies the importance of LOS as a postoperative outcome measure, and presents findings from a systematic literature review of factors that have been identified as being associated with LOS in previous studies of lumbar spine surgery.
- Chapter 3 marks the transition into the thesis research and comprises information on the study rationale and research objectives.
- Chapter 4 includes details on the study methodologies, including study population, data sources, study variables, and statistical analysis plan.
- Chapter 5 outlines the results of the study.
- Chapter 6 concludes by discussing the key results, strengths and limitations of the study, and implications for the Orthopedic Spine division and future research.

Chapter 2: Background & Literature Review

2.1. Orthopedic Disorders

Orthopedic disorders include injuries or diseases that affect the musculoskeletal system, including bones, tissues, tendons, and ligaments (13), and are a major source of chronic pain and disability worldwide (14). The Ontario Health Survey reported that musculoskeletal conditions were responsible for "40% of all chronic conditions, 54% of all long-term disability, and 24% of all restricted activity days" (14,15). The prevalence of musculoskeletal conditions increases with age, making Canada even more susceptible to the growing burden due to its aging population (14,16). While conditions affecting the musculoskeletal system vary greatly in pathophysiology, they share similarities anatomically, and with their adverse effects on pain and physical functioning (14).

2.2. Lumbar Spine Pathologies and Low Back Pain

LBP is a common condition that most people experience at some point in their life, with a lifetime prevalence as high as 84% (5). LBP poses a significant economic, societal, and health burden. According to the Global Burden of Disease 2016 Study, LBP was recognized as the leading cause of disability (measured in years lost due to disability) in those age 25-64 years (2,17,18). Due to a global population that is aging and increasing in size, the impact of LBP is steadily rising (19). It is not surprising that disability caused by LBP has a direct impact on the economic burden, as individuals are required to take time away from work (20,21). A systematic review of LBP cost of illness studies found that indirect costs from lost work productivity represented a majority of the total cost associated with the condition (22). At the individual level, the economic burden of LBP has profound implications. It is the leading chronic health problem forcing people to stop working and older adults to retire earlier (23). Furthermore, older adults that retire early due to LBP have approximately 87% less total wealth and income producing assets compared to those without LBP (24). The majority (~ 90%) of LBP cases are non-specific, in which there is not an obvious anatomical or structural cause (25–29).

While the majority of LBP cases are non-specific, a cause can be identified in a small proportion (~ 10%) of cases (28,30). A 2018 study by Ravindra et al. (1) estimated the annual global incidence of degenerative lumbar spine conditions with LBP to be 3.63% (266 million). LBP is commonly a symptom of degenerative lumbar spine pathologies, such as spondylolisthesis, spinal stenosis, disc herniation, or degenerative disc disease (20), which may be treated surgically.

The Canadian Spine Outcomes and Research Network (CSORN) provides a breakdown of the proportion of various spine pathologies in patients registered in the database (31). CSORN collects data from multiple centres across Canada on patients who have had a consultation with an orthopedic spine surgeon and plan to undergo surgery. There were 2322 patients enrolled in the CSORN database as of 2017; 79% had thoracolumbar health conditions and 21% cervical. Among thoracolumbar patients, 31% presented with stenosis as the principle pathology, 31% spondylolisthesis, 21% disc herniation, 7% degenerative disc disease, 6% deformity, 3% other, and 1% tumor (31). The following section includes information on the etiology,

pathophysiology, and epidemiology of degenerative lumbar spine conditions relevant to this thesis.

2.2.1. Spondylolisthesis

Spondylolisthesis is characterized by the forward slippage of a vertebral body, relative to the one below. Degenerative spondylolisthesis results from changes associated with age and commonly occurs at the L4/L5 region (32,33). Isthmic spondylolisthesis is caused by stress fractures and is most common at the lumbosacral region (L5/S1) (34). The prevalence of degenerative spondylolisthesis is highly dependent on age and gender. The ratio of prevalence in females compared to males is approximately 1.3 to one, and the risk is accelerated after the age of 50 (33). Spondylolisthesis is most often asymptomatic but often associated with spinal stenosis, and of the cases where symptoms are present, a small proportion will undergo surgery (34).

2.2.2. Spinal Stenosis

Spinal stenosis refers to the narrowing of the spinal canal and the associated symptoms caused by pressure on the spinal cord or nerves. It is most commonly caused by degenerative changes in the elderly population (35,36). It is more common in the lumbar spine, with the incidence being five times greater compared to the cervical region (5/100,000 vs. 1/100,000) (37). Lumbar spinal stenosis is estimated to affect over 200,000 adults in the US, with that number projected to rise exponentially in the next decade (38). It is also the primary reason for undergoing spine surgery in those over the age of 65 in the US (39,40). Spinal stenosis and degenerative spondylolisthesis share similar symptoms and surgical management (41).

2.2.3. Disc Herniation

In between the vertebral bodies (i.e. the bones) that make up the spine there are cushions known as intervertebral discs. These discs comprise tough fibers known as the annulus, which surround a gel-like substance called the nucleus. A herniated disc refers to the leakage of the inner nuclear material through the outer annulus, which can put pressure on the nerve roots and lead to pain and symptoms of numbness or weakness (42). Degenerative changes in the disc that occur with age contribute to disc herniation (42), with the highest prevalence being in those age 30 to 50 years (43). The incidence of disc herniation is estimated to be five to 20 per 1,000, with males having double the rate of occurrence compared to females (44). Other factors, such as physical exertion, trauma, and genetics can also influence the risk of disc herniation (45). More than 85% of patients that experience a herniated disc will improve on their own with time or conservative therapies (44); however, if pain and symptoms persist and surgery is required it usually includes a discectomy (46,47)

2.2.4. Scoliosis

Scoliosis is a deformity where the spine curves sideways, in the frontal plane (48). It can arise spontaneously (i.e. idiopathic scoliosis) or it can be related to degenerative changes or underlying medical conditions. The most common cause of scoliosis in adults is degeneration.

Prevalence estimates range between one to 10% (49,50), with a higher prevalence in older adults (51).

2.3. Lumbar Spine Surgery

There are many conservative therapies available to address degenerative lumbar spine conditions (52), and some will improve without intervention over time; however, when patients do not respond to alternative treatments or there are neurological abnormalities present, operative management is generally warranted (6). The majority of lumbar spine surgeries for degenerative spine pathologies are elective, meaning they are scheduled in advance.

The most recent study on the incidence of spine surgery in Canada was conducted in 1998. The study included routinely collected health data from five Canadian provinces (63% of the population) over a 12-month period and found that 12,329 spine surgeries were performed. The rate of spine surgery for the entire cohort was 80 per 100,000 individuals, which is lower compared to the US (53). Even with up-to-date epidemiologic data lacking, it is known that spine surgeries are prominent and show increasing rates (7). In the US alone, more than 500,000 surgeries are performed each year for degenerative lumbar spine disease (54,55). Studies have shown a sharp increase in lumbar fusion and laminectomy rates over the past two decades, with discectomy rates remaining fairly stable. For example, a study on elective lumbar spine surgery trends in the US reported a 56.4% increase in lumbar fusion procedures from 2003 to 2012 (8). A similar study in Belgium found laminectomy rates doubled from 2000 to 2009, without an increase in global rates of spinal disease (7). An Ontarian study reported a 63% increase in fusion rates for degenerative lumbar spine disease between 1995-2001 (56). It is unclear why rates of more invasive procedures such as spinal fusions are increasing in the absence of a parallel increase in indications. Potential explanations that have been proposed for these observed trends include the opinions of key stakeholders/leaders, financial incentives for hospitals or surgeons, the introduction of new surgical devices, and advances in peri-operative practices (57). In the CSORN 2017 registry (of which 1049 of the 2322 patients enrolled underwent surgery), approximately 55% of thoracolumbar surgeries were fusion (with or without other procedures), 11% discectomy, 23% decompression, and 11% combined discectomy and decompression (31). The most common operative indication for spine surgery is radiating leg pain from nerve root compression (58).

Elective spine surgeries consume significant hospital resources and are associated with high costs. In the US, the average hospital charges associated with complex fusions and decompressions are estimated to be $80,888 and $24,000, respectively (59). Between 1998 and 2008, there was a 3.3-fold increase in the average total hospital costs associated with spinal fusion discharges in the US (54). To compare to other common orthopedic surgeries, such as hip replacement and knee arthroplasty, these charges increased 2.2-fold and 2.3-fold, respectively, during the same decade. Looking at data from 2008, the bill for spinal fusion surgery on a national level was estimated to be $33.9 billion in the US – a number that increased 7.9-fold from the previous decade (54).

Common outpatient lumbar spine surgeries include non-instrumented discectomies and laminectomies. Common inpatient lumbar surgeries include multilevel laminectomies, and

instrumented fusions (60,61). The following section discusses various surgical procedures relevant to this thesis, including the clinical indications, surgical practices, prognoses, and evidence about expected LOS.

2.3.1. Discectomy

A discectomy involves the surgical removal the disc material that is pressing on the nerve root causing pain and symptoms (62). It is a common procedure to relieve unrelenting pain and discomfort caused by disc herniation (44,46,47). The most common surgical technique is called a microdiscectomy and uses a smaller incision (62,63). According to the Mayfield Clinic, the majority of patients will be discharged on the same day of surgery, while others will require a stay of one to two days (64).

2.3.2. Laminectomy (with or without Fusion)

Laminectomy, also known as a decompression, is a surgery that creates space within the spinal canal by removing the portion of bone at the back of the vertebrae called the lamina (65). This procedure is typically done with or without a fusion to treat spinal stenosis and degenerative spondylolisthesis (41). As per a report by the Mayfield Clinic, most patients who receive a laminectomy will stay one to two days in hospital (66). A 2015 retrospective cohort study on elective laminectomy for lumbar spinal stenosis reported an average LOS of 2.1 days (standard deviation (SD) = 2.6) for the cohort (67). According to the Ottawa Hospital, if a fusion is also required, a patient can expect to stay approximately four days in hospital (68).

2.3.3. Fusion

A spinal fusion is a surgical procedure that connects at least two vertebrae with the goal of stabilizing the spine. The vertebrae are fused together using bone graft, metal rods, and screws (69). These procedures are used to treat several spinal conditions and ailments, including vertebral fracture (70), deformity, instability, and most commonly, degenerative conditions such as spondylolisthesis and spinal stenosis (71). According to information from the North American Spine Society, patients usually stay in hospital for three to four days after surgery; however, LOS is variable and can be longer for more extensive surgeries or patients who are elderly or in a poor health state (71).

There are various approaches that are used for spinal fusion surgery. The most common techniques for treating degenerative conditions and instability are anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF) (72). Interbody fusions are different in the sense that disc material is removed and the anterior portion of the vertebrae (i.e. vertebral bodies) are also fused together. These are some of the most common procedures performed by spine surgeons, especially TLIFs (73). TLIF employs a one-sided posterior lateral approach, which is beneficial in terms of injury/recovery (74). In regard to differences and similarities in the mean LOS for PLIF, TLIF, and ALIF surgery that have been reported in the literature, a study in the US compared outcomes after open versus minimally invasive TLIF surgery. They reported an average LOS of 2.0 days (SD = 0.64) for the group that had the minimally invasive approach and an average stay of 3.0 days (SD = 1.26) for

those who received the open approach (75). In comparison, a study looking at elective, open PLIF reported a mean LOS of 3.6 days (SD = 1.8) for the study cohort (73). A similar study of both minimally invasive and open PLIFs reported an average LOS of 2.9 days (SD = 1.8) (76). A retrospective cohort study of 416 consecutive patients undergoing ALIF surgery reported an average LOS of 3.6 days (SD = 2.6) and 4.0 days (SD = 1.6) for patients who received a threaded versus nonthreaded interbody spacer device, respectively (77).

2.4. Important Outcomes for Lumbar Spine Surgery

Elective spine surgeries utilize significant hospital resources and the associated costs and outcomes after spine surgery are important considerations (54,55,78). There is a consistent emphasis in the healthcare system to reduce costs, improve efficiency, and maintain/improve care delivery while avoiding harm (79). Considering postoperative outcomes is one method for evaluating resource utilization, efficiency, and health care delivery. Important postoperative outcomes include duration of hospital stay (i.e. LOS), readmission to hospital/reoperation, complication rate, and patient reported outcomes such as pain, physical function, and health-related quality of life (80). Many of these outcomes are interrelated and should be considered in the context of one another. For instance, unnecessarily long LOS may suggest poor quality of care and increase the risk of hospital acquired infections (11). The interplay of various postoperative outcomes is demonstrated in a patient-centered LOS reduction intervention that was implemented in a US hospital. This initiative resulted in reduced average LOS by 7.8%, rates of readmission by 14.8%, incidence of patient safety indicators by 32%, healthcare acquired conditions by 55%, and an estimated yearly cost savings of $2.2 million (12). On the other hand, being discharged too early may lead to poorer patient outcomes and increased risk of readmission (11) (and hospital costs). For example, a study comparing 27 countries found that patients hospitalized in countries with longer average LOS for acute heart failure had significantly lower readmission rates (81). A study by Southern et al. (82) controlled for patient-level variables and found that shorter LOS was significantly associated with a higher risk of 30-day, all-cause mortality. These potential tradeoffs should be carefully considered when looking at policies/incentives that aim to shorten LOS.

2.4.1. Length of Stay

Inpatient LOS following surgery is an especially important outcome measure for hospital administrators to consider. It is important from both a patient and system perspective as it is associated with hospital costs, efficiency, quality of care delivered, and clinical outcomes (6,9). LOS is commonly used as a proxy for understanding resource utilization within hospitals (9,79), and patients with prolonged LOS have considerably greater resource use.

Inpatient costs associated with elective lumbar spine surgeries are closely related to a patient's LOS. The estimated baseline cost for every extra day spent in hospital following spine surgery in the US is $1,000 (10), with these costs reported to be rising (83). According to recent estimates from a study conducted in Nova Scotia, the average costs of admission for three similar spine surgical procedures was approximately $1,100 per day (84). In terms of patient experiences and outcomes, prolonged LOS is correlated (though not causally) with adverse events such as deep vein thromboses (85). A study of adverse events in Canadian hospitals found that patients who

experienced adverse events had longer hospital stays compared to those who did not have adverse events (86). Furthermore, the costs associated with these intra- or post-operative complications can be higher (87). LOS is also an essential variable to consider with regard to hospital scheduling and resource management (9,88).

These associations have led to increased efforts to better quantify and improve resource use and unnecessary days spent in hospital (89). Identifying factors associated with increased LOS requires complex evaluation strategies since LOS is influenced by many surgical and nonsurgical factors (90). For instance, LOS can be influenced by the patients' demographics and health state, availability of services and extended care facilities (91), and differences between surgical practices (89).

LOS is commonly measured in the literature from the day of surgery to the day of discharge, with no compensation for partial days (92–94). How extended LOS is defined for analysis purposes varies in the literature, with definitions ranging from greater than 24 hours to greater than seven days. Some studies use data-driven and somewhat arbitrary approaches for deciding what constitutes extended LOS for various lumbar spine procedures. For example, Gruskay et al. (73) defined extended LOS as being at least one standard deviation greater than the mean. McGirt et al. (95) used a cut-off of more than seven days and applied it to a heterogenous surgical spine population. Using data driven thresholds in the absence of clinical justification can lead to spurious associations and results. The categorization of LOS also makes it difficult to compare to other studies that use different definitions of extended LOS. There is no consensus on what constitutes extended LOS in the surgical spine literature, and there is likely considerable variation by surgical procedure (e.g. discectomy vs. interbody fusion). There is, however, a consensus in the epidemiologic literature for the use of linear or non-linear modeling of continuous variables versus categorization (96). We carefully reviewed the LOS and surgical spine literature and decided it would be most appropriate to consider the outcome LOS continuously. A summary of how various studies in the field have defined extended LOS can be found in Appendix A.

2.5. Literature Review: Factors Associated with LOS After Elective Lumbar Spine Surgery

There is limited literature considering LOS as a primary outcome following various types of elective spine surgeries. Based on a systematic literature search, we identified seven retrospective cohort studies (90,95,97–101) on this topic that focus specifically on lumbar spine surgery.

These studies have identified several modifiable and non-modifiable factors associated with prolonged LOS in patients undergoing elective lumbar spine surgery. The results from this systematic literature search, including the effect measures, are summarized in Appendix B and presented below. There is inconsistency among the preoperative, operative, and postoperative factors identified across studies. We developed a theoretical framework to assess the literature (see Figure 1).

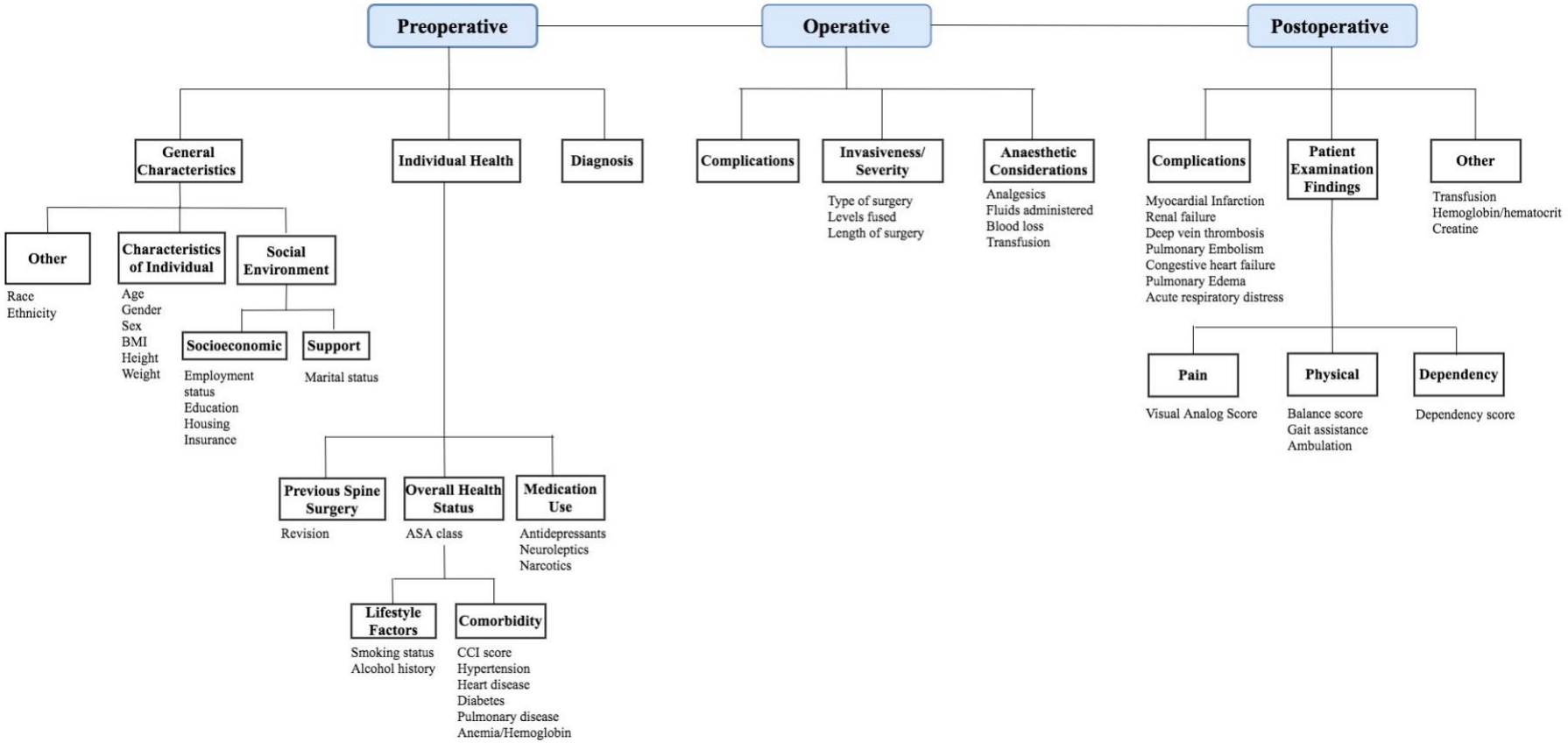

Figure 1. Theoretical framework of prognostic factors found in the literature to be related to LOS after lumbar spine surgery.

2.5.1. Preoperative Factors

Several studies in lumbar fusion surgery have identified chronological age (92,95,97,102) and American Society of Anesthesiology (ASA) class (92,95,97) as having a statistically significant independent association with extended LOS. Other factors include morbid obesity (body mass index (BMI) ≥ 40) (92), hemoglobin levels, oxycodone use (94), ambulation (independent vs. assisted), Oswestry Disability Index score (≥ 70), and diabetes (95). In one study, chronological age was identified as having the largest adequately adjusted association with LOS out of three preoperative variables reported to be associated, with each decade of age beyond 40 years adding approximately 0.33 days to LOS (92). Preoperative variables that have been identified as not having a significant association with extended LOS upon multivariable analysis include sex, smoking history, alcohol history, diabetes, cardiac disease, and pulmonary disease (92). Conversely, studies have also found baseline patient comorbidities to not be associated with extended LOS and suggest that differences in surgeon preference/practice may be responsible for the variations in LOS (6,89).

In lumbar laminectomy surgery, Basques et al. (98) identified increasing age, increasing BMI, and ASA class ≥ 3 to be associated with extended LOS using multivariable analysis. A similar study (57) found that age, sex, race, comorbidity index, previous spine surgery, and number of hospitalizations in the past year to be associated with LOS following lumbar laminectomy surgery; however, no adjustments were made for potential confounders.

2.5.2. Operative Factors

There are several factors related to surgery that have been identified as having a statistically significant association with LOS. Basques et al. (92) found that operative time, multilevel procedure (with level referring to the vertebral level, and one-level constituting the instrumentation of two vertebrae), and intraoperative transfusion were significantly associated with extended LOS following elective posterior lumbar fusion surgery. Intraoperative transfusion had the largest overall association with extended LOS. Contrary to findings from Basques et al. (92), Gruskay et al. (97) found that the number of vertebral levels fused was not associated with LOS. In another study, intraoperative fluid usage, fluid balance, intraoperative colloids, crystalloid to colloid ratio, and mean percentage of fraction of inspired oxygen were identified as having a statistically significant independent association with LOS after lumbar fusion surgery (94). It should be noted that patients with a stay greater than 24 hours were considered in the extended stay cohort. The average LOS for lumbar fusion is approximately four days (103); therefore, the clinical significance of this cutoff should be questioned.

2.5.3. Postoperative Factors

Similar to intraoperative prognostic factors, postoperative characteristics are not as extensively studied in the literature compared to preoperative factors. In one of the few articles to identify postoperative factors, Siemionow et al. (94) found postoperative creatine and visual analogue scale for pain to be significantly associated with LOS upon multiple regression analysis. Kanaan et al. (2015) identified factors significantly associated with LOS and used them to develop a structural equation model to predict LOS. The model separated the independent variables into

three latent factors: presurgical, surgical, and postsurgical. The postsurgical factor was indicated by walking distance, level of walking assistance, balance scores, and bed mobility and transfer dependency scores. Compared to the presurgical and surgical factors, the postsurgical factor had the strongest independent effect on LOS, explaining 19% of the variability.

2.6. Gaps and Limitations in the Literature

Many studies in the field suffer from methodological limitations. For example, the majority of studies use stepwise regression techniques as selection tools for multivariable modelling as opposed to more clinically driven selection methods. Stepwise regression tends to overestimate effect sizes and overall model fit (104). Previous studies have also considered extended LOS as a dichotomous variable and used data driven cut points to define what constitutes extended stay. Importantly, research on this topic has not been done in the Nova Scotian population. Postoperative care varies among individual surgeon practice and by hospital/region, as do the clinical characteristics of the patient population (6). Thus, previous findings may not be generalizable to the local institution and patient population (103). Factors that were supported by little or no evidence but included in the theoretical framework for this thesis are postoperative transfusion, postoperative hemoglobin, Charlson comorbidity index, smoking status, preoperative neuroleptic use, and intraoperative analgesics. The rationale for including these characteristics was for both clinical and exploratory reasons.

Chapter 3: Thesis Research and Study Objectives

Lumbar spine disease poses a significant burden at both the individual and societal level, and the high healthcare systems costs and postoperative outcomes (including extended LOS, readmission, and adverse events) associated with surgery are of concern. Inpatient LOS is an invaluable parameter for evaluating resource utilization and quality of care. More specifically, studying the patient, clinical, and surgical characteristics associated with a longer LOS may provide an opportunity for improved resource use and inpatient flow. Previous exploratory studies have identified a host of factors to be associated with longer LOS following lumbar spine surgery; however, research is limited and findings are inconsistent. With patient and regional factors contributing significantly to a patient's LOS, it is important that this research has not been conducted at the local institution. Additionally, further research is required in order for future confirmatory prognostic studies to be conducted and prediction models developed and tested. Studying LOS following elective lumbar spine surgery and the factors that are associated with longer LOS has valuable implications for the Orthopedic Spine division, patients, and future research, which leads to the primary objective of the proposed research.

3.1. Objectives

1) The initial objective of this research is to describe the distribution of the demographic, clinical, operative, and postoperative characteristics among patients undergoing elective lumbar spine surgery for single- and two-level degenerative conditions at a Nova Scotian quaternary care institution between October 2014 to October 2016.

2) The primary and analytic objective of this research is to describe how the demographic, clinical, operative, and postoperative characteristics are independently associated with LOS among the study population.

Chapter 4: Methods

4.1. Study Design and Setting

This research builds off an interim analysis conducted by the author as part of an honours research project at Dalhousie University within the Department of Kinesiology in the school of Health and Human Performance (103). We used a retrospective cohort design and abstracted data from patients' electronic medical charts at a quaternary academic teaching hospital in Halifax, Nova Scotia. Ethical approval was obtained from the Institutional Research Ethics Board (Romeo No. 1022544).

4.2. Study Population

We used a purposeful sampling technique (i.e. non-probability sampling) called total population sampling to select study participants. We included consecutive patients who underwent elective lumbar spine surgery for degenerative conditions by one of two orthopedic spine surgeons between October 2014 and October 2016. These two orthopedic spine surgeons perform approximately 90% of all orthopedic spine surgeries for patients residing in Nova Scotia. Thus, we believe our sample to be fairly representative of all patients undergoing surgery for a degenerative lumbar spine disorder by an orthopedic spine surgeon at a Nova Scotian quaternary care centre. See Appendix D for defined study populations used in previous literature in the field. Previous studies have mainly focused on a specific spinal surgery (e.g. TLIF), whereas this research will include multiple surgical groups, similar to McGirt et al. (95).

All patients who underwent elective lumbar spine surgery, including laminectomy, discectomy, 1-level TLIF, 2-level TLIF, and ALIF, for degenerative conditions of the lumbar spine were assessed for inclusion. We included the first operation for patients who had more than one surgery during the study window. Other reasons for exclusion were non-elective/non-lumbar surgery, patients under the age of 18, surgery performed outside of the study window, and LOS of 30 days or more.

4.3. Data Sources

We used International Classification of Diseases ninth revision billing codes for the surgeons' caseloads between October 2014 to October 2016 to identify potentially eligible participants (see Table 1 for a description of the specific billing codes used). After participants were identified, we pulled their electronic medical charts (that are used for administrative purposes) and abstracted the factors of interest. We entered data into Microsoft Excel version 15.41 (105) and stored the data file on a secure Nova Scotia Health Authority network, protected by a password. All variables were coded by the data abstractor using a data dictionary (Appendix C), except for surgery group, surgical diagnosis, and intra- and post-operative complications, as these variables require more advanced clinical knowledge. These variables were transcribed from the patients' electronic record by the data abstractor and later coded by Surgeon 1. We used personal health information in the most de-identifiable form possible by assigning each participant a unique study ID and deleting personal identifiers, including health card number, date of birth, and admission-, surgical-, and discharge-date, after the data were cleaned and coded.

Table 1. International Classification of Diseases ninth revision codes used to identify patients.

Billing Code	Description
7244	Thoracic/lumbosacral neuritis/radiculitis, unspecified
7245	Backache, unspecified
7242	Lumbago
7231	Cervicalgia (neck pain)
8069	Unspecified vertebral fracture with cord injury
72981	Swelling of limb
7272	Specific bursitis often of occupational origin
7295	Pain in limb
7273	Other bursitis
72402	Spinal stenosis lumbar region

We adhered to the methodologic considerations for conducting retrospective chart reviews by Vassar and Holzmann (106). One reviewer performed the data abstraction in full. They carefully trained and coded several patients for practice under supervision from another member of the research team. The data abstraction form was developed and piloted *a priori* and organized in accordance to the order in which data were presented in the medical record. This should have helped to improve the reliability of the data and reduced errors in recording. All variables were also operationalized ahead of time, including where in the medical chart the information is located (see Appendix C).

4.4. Data Quality

Due to feasibility issues, we were not able to perform re-abstraction on 10% of the dataset and compute a Cohen's kappa coefficient as initially stated in the thesis proposal document. Rather, we computed the percent agreement between two abstractors for four variables as a measure of inter-rater reliability. Prior to the initiation of data abstraction for this study, another researcher at the institution abstracted data on four overlapping variables for a separate study using an overlapping study population (n = 763). These variables included operative time, operating surgeon, revision surgery, and service date (from which LOS was computed). For the variable operative time, a difference greater than five minutes was considered a disagreement.

We explored and quantified missingness in the data. Based on observations during data abstraction, we anticipated that there may be issues with respect to missingness in comorbidity data. For individual comorbidities used to calculate the Charlson comorbidity index score, we assumed missing values as being without the condition (coded as zero). Underlying this decision is the assumption that if a comorbid condition was present, it would be indicated in the anesthesia record, the individual patient questionnaire, or the initial clinical consultation note from the surgeon.

4.5. Independent Variables

Data were abstracted for 22 pre-, intra-, and post-operative variables that fit within the theoretical framework of prognostic factors that we developed based on previous literature (see Figure 1). The variables we abstracted data on are presented here in bold text, while the concepts from the model under which the variables fit are presented subsequently in italics.

4.5.1. Preoperative

The preoperative variables we abstracted data on included **sex, age, BMI** (*general characteristics; characteristics of individual*), **revision surgery** (*individual health; previous spine surgery*), **ASA class** (*individual health; overall health status*), 19 comorbidities in order to calculate **Charlson comorbidity index score**, including **cerebrovascular disease, myocardial infarction, congestive heart failure, peripheral vascular disease, chronic pulmonary disease, ulcer disease, liver disease, diabetes, connective tissue disease, hemiplegia, renal disease, AIDS, metastatic tumor, lymphoma, leukemia, non-metastatic tumor,** and **dementia** (*individual health; overall health status; comorbidity*), **smoking status** (*individual health; overall health status; lifestyle factors*), **Workers' Compensation Board (WCB) claim** (*general characteristics; social environment; socioeconomic*), **hemoglobin level** (*individual health; overall health status; comorbidity*), **narcotic use** (type and dose), **antidepressant use, neuroleptic use** (*individual health; medication use*), and **initial diagnosis**.

ASA class is a global measure of physical status before surgery and ranges from one to five, with a score of three indicating severe systemic disease (107). ASA class was recorded as an integer but considered as a dichotomous variable (< 3 vs. ≥ 3), which is the categorization that other studies have used (92,95). The co-morbid conditions were considered as a single categorical variable, represented by the Charlson comorbidity index score. To calculate the Charlson comorbidity index, each comorbidity is assigned a weight from one to six based on risk of mortality and severity of disease. The weights are then summed to provide a total score (see Appendix E). The Charlson comorbidity index has been used extensively and been validated in a number of clinical populations and settings (108,109).

4.5.2. Operative

The operative factors we abstracted data on included **analgesics** (type and dose)**, blood transfusion, estimated blood loss** (*anaesthetic considerations*), **surgical case time, surgery performed** (*invasiveness/severity*), **complications**, and **operating surgeon**. Length of surgery is generally associated with more complex cases and may be caused by intraoperative complications that can lead to a greater volume of blood loss, increased fluid infusion, and lower end case temperature (92,94).

4.5.3. Postoperative

The two postoperative factors we abstracted data on were **hemoglobin level** and **transfusion** (*other*). We did not abstract data on postoperative complications due to feasibility and because of the anticipated close relationship with the outcome variable (97). Refer to Appendix C for a

complete description of the variables, how they were coded, and where they are located within the electronic medical record.

4.6. Outcome Measure

The outcome variable was postoperative LOS, calculated from the date of surgery to the date of discharge (yyyy-mm-dd), with no accommodation for partial days. LOS was considered as a continuous variable in order to quantify the magnitude of effect of each risk factor on LOS using multivariable modelling and to optimize study power. Patients with a LOS of 30 days or more were excluded from the analysis as their LOS is likely to encompass alternate level of care days that are due to reasons unrelated to surgery (e.g. awaiting a long-term care bed or a concurrent musculoskeletal disorder impacting mobility allowing for safe home discharge, etc.) (110).

4.7. Statistical Analysis Plan

We used StataIC version 15.1 (111) to perform all analyses. Statistical significance was considered at the 0.05 level. As a post-hoc addition we interpreted a risk ratio (RR) of < 1.5 to be weak, 1.5-3 to be moderate, and > 3 to be strong.

4.7.1. Objective 1: Descriptive

We used descriptive statistics to summarize the clinical characteristics of the patient population. For categorical variables we used count and percent frequency, and for continuous variables we used mean, 95% confidence interval (CI), and range. We also described the LOS for each independent variable, including median, interquartile range (IQR), mean, and range. To determine the distribution of the outcome variable LOS, we used exploratory analyses. In addition to describing the population as a whole, post-hoc we stratified by surgery group for 1-level TLIF, laminectomy, and discectomy (there were insufficient sample sizes to include 2-level TLIF and ALIF).

4.7.2. Objective 2: Analytic (Associations with Length of Stay)

We assessed the relationship between LOS and each prognostic factor under bivariate analyses using simple Poisson regression. We developed a multivariable regression model to identify prognostic factors that are independently associated with LOS for lumbar spine surgery for degenerative conditions. We stratified by surgery group for 1-level TLIF, laminectomy, and discectomy in order to explore heterogeneity within the study population. We used multiple quasi-Poisson regression to handle the outcome values of zero (i.e. patients who were discharged on the same day as surgery and had a LOS of zero days).

We explored multicollinearity between variables thought to be measuring similar concepts. As per the theoretical framework presented in Figure 1, we explored multicollinearity for the following variables: Charlson comorbidity index score and ASA class, surgical procedure and operative time, and intraoperative complications and operative time. We intended to explore multicollinearity for intraoperative and postoperative blood transfusion, and preoperative hemoglobin and transfusion; however, we were unable to do so because of insufficient power

(cell sizes < 5). We assessed multicollinearity by computing a bivariate correlation and variance inflation factor (VIF) and using a sensitivity analysis to examine how coefficients change. We used a correlation coefficient > 0.7, VIF > 10, and a change in beta coefficients > 20% as indicators of potential multicollinearity issues. When potential multicollinearity was present, we selected the variable we thought best captured the concept being measured.

The guiding principles we used for selection of variables for inclusion in the multivariable model included the following:

1) Clinical utility (e.g. can the factor be easily abstracted from the patients' medical record and is it modifiable?).

2) Previous literature (e.g. has it shown a statistically significant association with LOS in previous literature?).

3) Results from statistical exploration of multicollinearity, which were decided *a priori* and based on the conceptual model and clinical knowledge.

4.7.3 Sensitivity Analysis

Post-hoc we performed a sensitivity analysis excluding patients with a diagnosis of degenerative scoliosis to determine if there was heterogeneity within these patients that impacted the results. While these patients were coded as having a degenerative lumbar spine condition (not a major deformity), scoliotic patients could differ in terms of how various factors impact LOS compared to other conditions included within the study population. Spinal surgery for this patient population can be more heterogenous compared to other degenerative lumbar spine pathologies.

Chapter 5: Results

5.1. Study Population

Application of the diagnostic billing codes in Table 2 to both surgeons individually resulted in 423 encounters for Surgeon 1 and 421 encounters for Surgeon 2 (Total n = 844). Duplicates were removed for 74 surgeries that both surgeons operated on together. Seven surgeries were excluded for billing code errors observed on full chart review (e.g. spine billing code applied to ankle surgery). Full data were abstracted on 763 spinal surgery patients. The following exclusion criteria were then applied in sequence: date range (October 2014 to October 2016), initial diagnosis (non-degenerative non-lumbar spine pathology), surgery performed (non-elective non-lumbar spine surgery), age < 18 years, duplicate patients (patients who underwent more than one surgery within the study window), and LOS ≥ 30 days. A total of 473 individual patients who underwent elective lumbar spine surgery met inclusion criteria and were included in the final study sample. See Figure 2 for a flow diagram of the study population selection process.

5.2. Objective 1: Descriptive

The average age of patients in the entire cohort was 59.6 years (95% CI: [58.3, 61]), and 48.4% were female. Nearly half (46%) of patients were classified as obese (BMI ≥ 30 kg/m2), 17% had a normal BMI (18.5-24.9 kg/m2), and 37% were overweight (BMI = 25-29.9 kg/m2). The majority of patients (94.1%) had a Charlson comorbidity index score below three: 62.8% had a score of zero, 21.6% had a score of one, and 9.7% had a score of two. In terms of preoperative medication use, 34.5% of patients were taking antidepressants, 28.3% were taking narcotics, and 35% were taking neuroleptics. The median LOS for the patient population was 3.0 days (IQR = 1-4), with a range of 0-25 days. LOS was right skewed: 91 patients (19%) stayed zero days in hospital, while 56 patients (11.8%) stayed one week or longer. A summary of the clinical characteristics of the patient population, both overall and stratified by surgery group, can be found in Table 2. Figure 3 displays the distribution of LOS for the entire patient sample and Figures 4-6 provide the distribution of LOS stratified by surgery group. LOS (including median, IQR, mean, and range) for each study variable can be found in Appendix F.

5.2.1. 1-level TLIF

A total of 189 patients (40% of the entire study population) underwent a 1-level TLIF. The average age for these patients was 63.5 years (95% CI: [61.7, 65.3]), and 57% (n = 108) were female. Approximately half of 1-level TLIF patients had a BMI in the obese range, one-third in the overweight range, and 16% in the normal range. Ninety-one percent of 1-level TLIF patients had a Charlson comorbidity index score below three and 28% of procedures were revisions. The median LOS for patients undergoing a 1-level TLIF was 4.0 days (IQR = 3-6).

5.2.2. Discectomy

A total of 124 patients (26% of the entire study population) underwent a discectomy. These patients were younger compared to the other surgery groups, with an average age of 45.6 years (95% CI: [43.1, 48.1]). Approximately half of all discectomy patients (n = 64) were female.

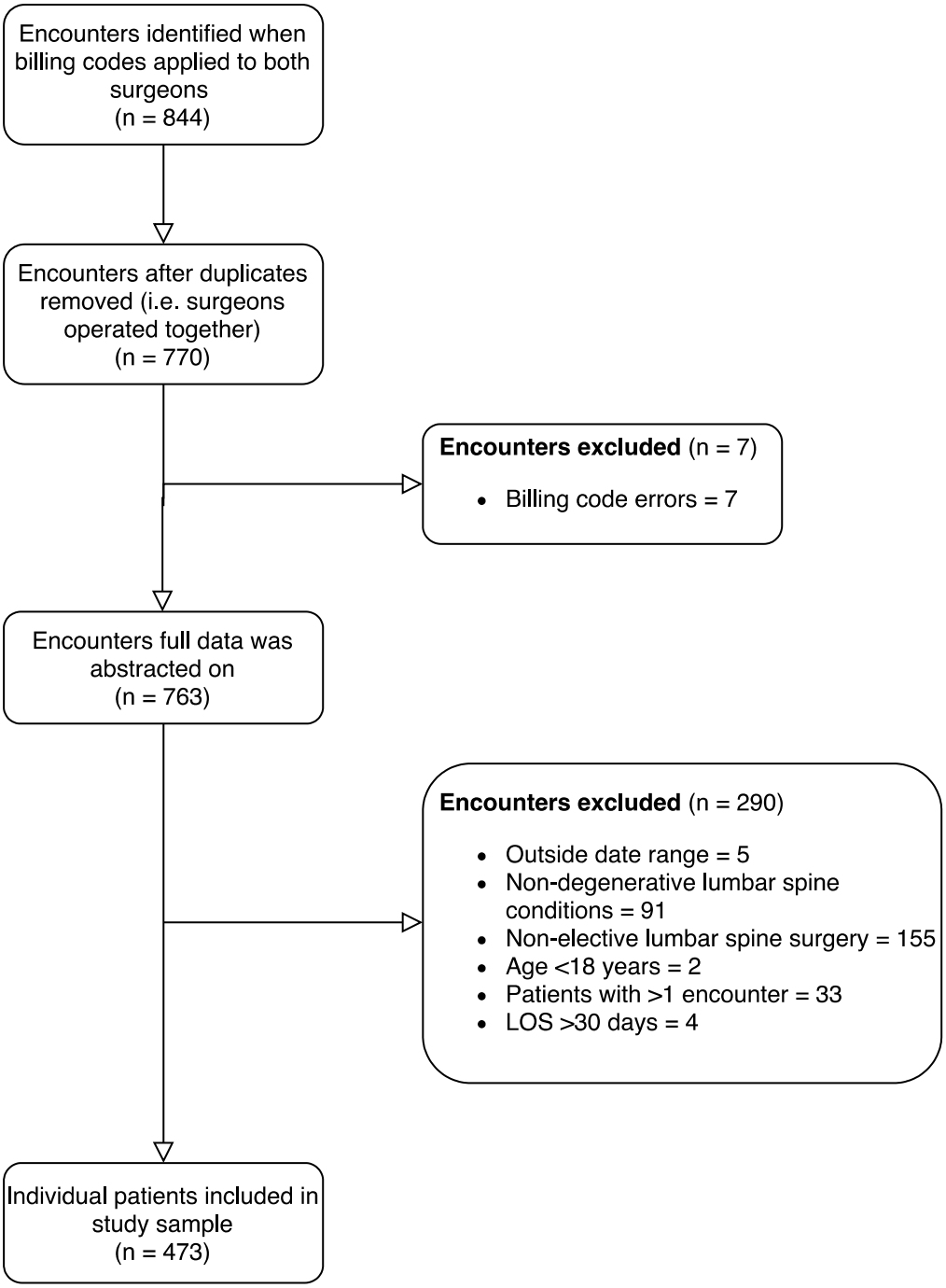

Figure 2. Flow diagram for the selection of the study population.

Thirty-eight percent of discectomy patients had a BMI in the obese range, 41% in the overweight range, and 21% in the normal range. All discectomy patients had a Charlson comorbidity index score below three and a small proportion (9%) of procedures were revisions. The median LOS for patients undergoing a discectomy was 0 days (IQR = 0-1).

5.2.3. Laminectomy

A total of 90 patients (19% of the entire study population) underwent a laminectomy. The average age for these patients was 67.1 years (95% CI: [64.7, 69.5]), and 27% (n = 24) were female. Approximately half of all laminectomy patients had a BMI in the obese range, 36% in the overweight range, and 13% in the normal range. Nearly all laminectomy patients (94%) had a Charlson comorbidity index score below three and 18% of procedures were revisions. The median LOS for patients undergoing a laminectomy was 2.0 days (IQR = 1-4).

Blood loss was not reported due to substantial missingness (n = 310; 66%) and poor clinical utility of the estimate itself (i.e. not meeting principle one for model selection). It is well established in the literature that visual estimation of intraoperative blood loss (while the most commonly used method) is inaccurate (112,113). Postoperative hemoglobin was also not reported on due to substantial missingness (n = 159; 34%) and inconsistency in the date it was measured among patients. Intraoperative complications were grouped into dural tear (i.e. minor complication) vs. major complication due to the small number of major complications. Major complications that occurred intraoperatively in the study cohort were vascular injury, neural injury to the nerve root, massive blood loss, and implant/instrument related complication.

Table 2. *Clinical characteristics of the patient population, overall and stratified by surgery group.*

Variables	Total sample N = 473 (%)	1-level TLIF N = 189 (%)	Discectomy N = 124 (%)	Laminectomy N = 90 (%)
LOS (days) **Median (IQR), range*	3 (1-4) 0-25	4 (3-6) 1-25	0 (0-1) 0-12	2 (1-4) 0-21
Preoperative				
Sex				
Male	229 (48.4)	81 (42.9)	60 (48.4)	66 (73.3)
Female	244 (51.6)	108 (57.1)	64 (51.6)	24 (26.7)
Age (years) **Mean (95% CI), range*	59.6 (58.3, 61) 18.4-87.9	63.5 (61.7, 65.3) 18.4-87.9	45.6 (43.1, 48.1) 20.1-80.9	67.1 (64.7, 69.5) 38.1-86.0
BMI (kg/m2)				
Normal (18.5-24.9)	81 (17.1)	30 (15.9)	26 (21.0)	12 (13.3)
Overweight (25-29.9)	173 (36.6)	64 (33.9)	51 (41.0)	32 (35.6)
Obese (≥30)	219 (46.3)	95 (50.2)	47 (38.0)	46 (51.1)
ASA classification				
1-2	355 (75.0)	124 (65.6)	114 (91.9)	63 (70.0)
3-4	118 (25.0)	65 (34.4)	10 (8.1)	27 (30.0)
Revision surgery				
Yes	98 (20.7)	52 (27.5)	11 (8.9)	16 (17.8)
No	375 (79.3)	137 (72.5)	113 (91.1)	74 (82.2)
Smoking status				
Yes	136 (28.8)	51 (27.0)	50 (40.3)	20 (22.2)
No	337 (71.2)	138 (73.0)	74 (59.7)	70 (77.8)
CCI score				
0-2	445 (94.1)	172 (91.0)	124 (100)	85 (94.4)
≥3	28 (5.9)	17 (9.0)	0	5 (5.6)
Hemoglobin (g/L)				
<130	129 (27.2)	60 (31.7)	18 (14.5)	21 (23.3)
≥130	314 (66.3)	124 (65.6)	83 (66.9)	68 (75.6)
Missing	31 (6.5)	5 (2.7)	23 (18.6)	1 (1.1)
Preoperative narcotic use				
Yes	134 (28.3)	59 (31.2)	36 (29.0)	20 (22.2)
No	335 (70.8)	130 (68.8)	84 (67.8)	70 (77.8)
Missing	4 (0.9)	0	4 (3.2)	0
Preoperative neuroleptic use				
Yes	166 (35.1)	69 (36.5)	50 (40.3)	27 (30.0)
No	303 (64.0)	120 (63.5)	71 (57.3)	62 (68.9)
Missing	4 (0.9)	0	3 (2.4)	1 (1.1)
Preoperative antidepressant use				
Yes	163 (34.4)	74 (39.2)	37 (29.9)	20 (22.2)
No	305 (64.5)	114 (60.3)	83 (66.9)	70 (77.8)
Missing	5 (1.1)	1 (0.5)	4 (3.2)	0
WCB insurance status				
WCB claim	26 (5.5)	10 (5.3)	10 (8.1)	5 (5.6)
No claim	437 (92.4)	174 (92.1)	112 (90.3)	83 (92.2)
Missing	10 (2.1)	5 (2.6)	2 (1.6)	2 (2.2)

Variables	Total sample N = 473 (%)	1-level TLIF N = 189 (%)	Discectomy N = 124 (%)	Laminectomy N = 90 (%)
Initial diagnosis				
Degenerative spondylolisthesis	132 (27.9)	91 (48.1)	0	11 (12.2)
Isthmic spondylolisthesis	46 (9.7)	29 (15.3)	*5 (4.0)	*5 (5.6)
Disc herniation	139 (29.4)	10 (5.3)	114 (92.0)	9 (10.0)
Spinal stenosis	93 (19.7)	22 (11.6)	*5 (4.0)	60 (66.7)
Scoliosis	15 (3.2)	5 (2.6)	0	0
Hardware failure fixation in bone	*5 (1.1)	*5 (2.6)	0	0
Adjacent segment disease	32 (6.8)	20 (10.6)	0	*5 (5.6)
Non/mal-union	11 (2.3)	7 (3.7)	0	0
Operative				
Surgery group				
Laminectomy	90 (19.0)	-	-	-
Discectomy	124 (26.2)	-	-	-
1-level TLIF	189 (40.0)	-	-	-
2-level TLIF	50 (10.6)	-	-	-
ALIF	20 (4.2)	-	-	-
Intraoperative analgesics				
Hydromorphone (long acting)	308 (65.1)	133 (70.4)	79 (63.7)	52 (57.8)
Dose (mg) *Mean (95% CI), range*	0.96 (0.89, 1.0) 0.2-6	1.03 (0.91,1.2) 0.4-6	0.85 (0.73, 0.97) 0.2-3.6	0.84 (0.72, 0.95) 0.4-2
Morphine (long acting)	32 (6.8)	11 (5.8)	7 (5.7)	*5 (5.6)
Dose (mg) *Mean (95% CI), range*	7.9 (5.7, 10.1) 2-25	7.1 (3.7, 10.5) 2-20	7.3 (1.7, 12.9) 3-20	9.7 (-1.5, 20.9) 5-14
Fentanyl/remifentanil (short acting)	119 (25.2)	39 (20.6)	35 (28.2)	28 (31.1)
Missing	14 (3.0)	6 (3.2)	3 (2.4)	5 (5.6)
Operative time (min) *Mean (95% CI), range*	111.0 (106.1, 115.8) 34-459	126.2 (120.5, 131.8) 61-431	85.3 (78.5, 92.0) 36-414	79.5 (73.2, 85.8) 34-171
Operating surgeon				
Surgeon 1	234 (49.5)	78 (41.3)	97 (78.2)	39 (43.3)
Surgeon 2	227 (48.0)	106 (56.1)	22 (17.8)	46 (51.1)
Both	12 (2.5)	*5 (2.6)	*5 (4.0)	*5 (5.6)
Intraoperative transfusion				
Yes	*5 (1.1)	*5 (2.6)	0	0
No	451 (95.3)	176 (93.1)	121 (97.6)	84 (93.3)
Missing	17 (3.6)	8 (4.3)	3 (2.4)	6 (6.7)
Intraoperative complications				
Dural tear (minor)	25 (5.3)	6 (3.2)	7 (5.7)	5 (5.6)
Major	6 (1.3)	*5 (2.6)	*5 (4.0)	*5 (5.6)
None	442 (93.4)	178 (94.2)	112 (90.3)	80 (88.8)
Postoperative				
Postoperative blood transfusion				
Yes	8 (1.7)	*5 (2.6)	0	*5 (5.6)
No	452 (95.6)	182 (96.3)	116 (93.6)	84 (93.3)
Missing	13 (2.8)	2 (1.1)	8 (6.4)	1 (1.1)

*Cell sizes <5 were suppressed to minimize the risk of patient identification.
LOS = length of stay, IQR = interquartile range, CI = confidence interval, BMI = body mass index, ASA = American Society of Anesthesiology, CCI = Charlson comorbidity index, WCB = Workers' Compensation Board, TLIF = transforaminal lumbar interbody fusion, ALIF = anterior lumbar interbody fusion.

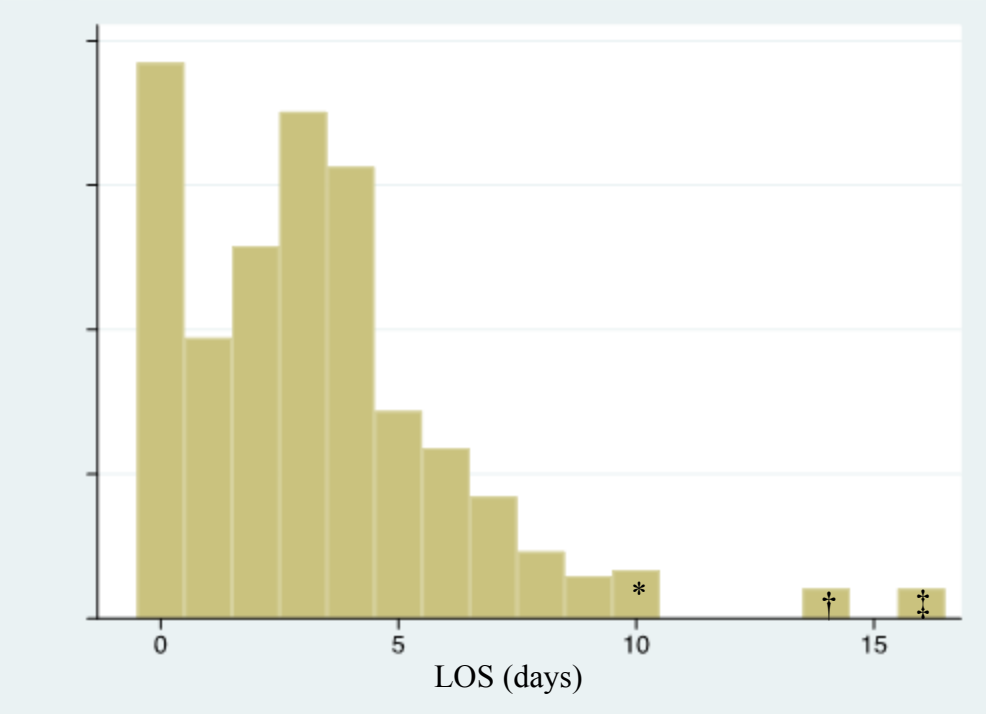

Figure 3. *Histogram showing the distribution of LOS for the entire sample (note that LOS was combined between 10-12 days (*), 14-15 days (†), and 16+ days (‡) due to cell sizes < 5).*

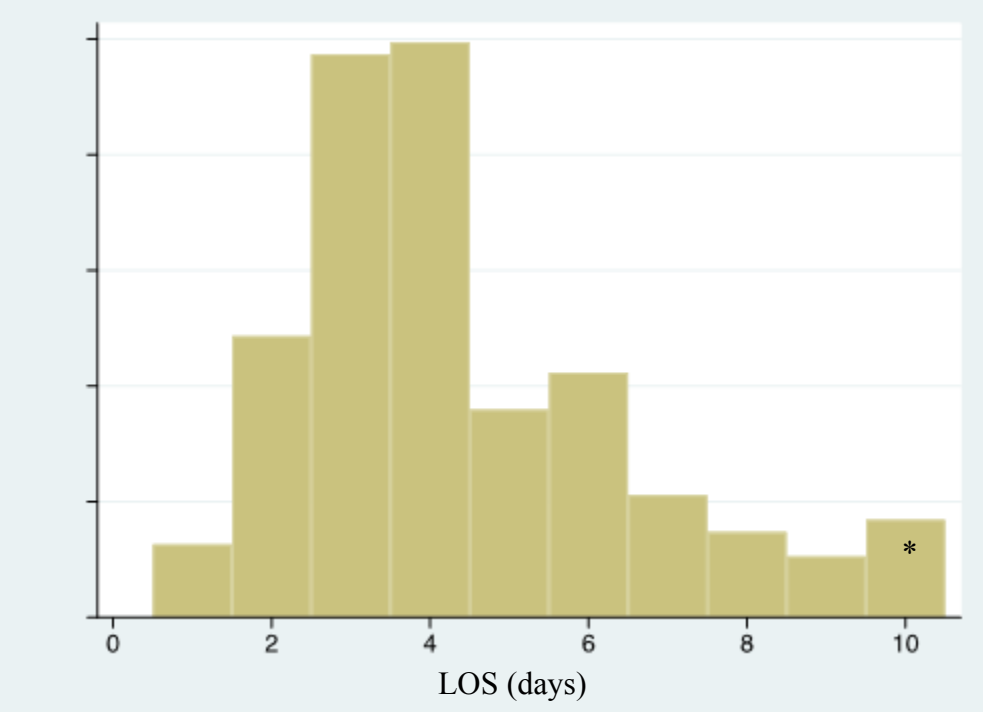

Figure 4. *Histogram showing the distribution of LOS for 1-level TLIF patients (note that LOS was combined for 10+ days (*) due to cell sizes < 5).*

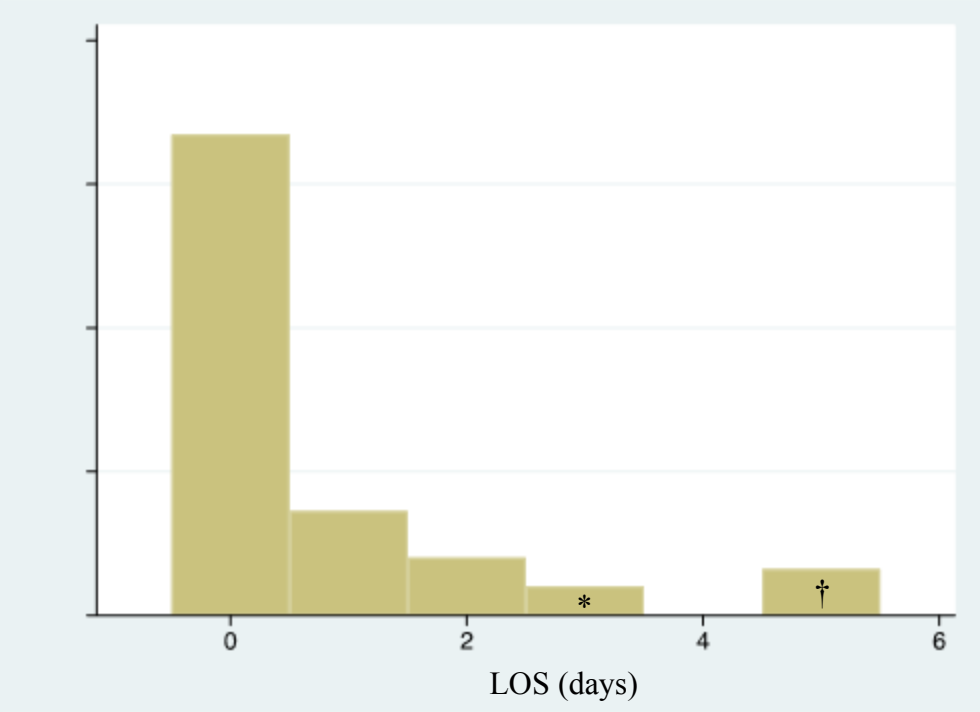

Figure 5. *Histogram showing the distribution of LOS for discectomy patients (note that LOS was combined for 3-4 days (*) and 5+ days (†) due due to cell sizes < 5).*

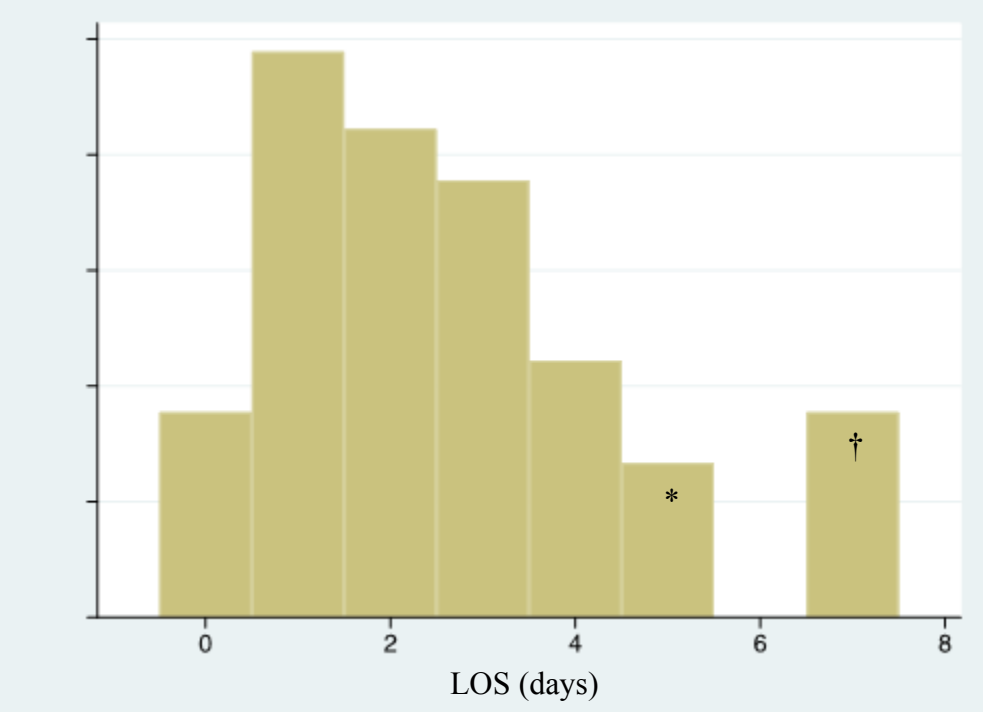

Figure 6. *Histogram showing the distribution of LOS for laminectomy patients (note that LOS was combined for 5-6 days (*) and 7+ (†) days due to cell sizes < 5).*

5.3. Objective 2: Associations with Length of Stay

Results from bivariate analyses of each independent variable with LOS are presented in Table 3. Several variables showed a statistically significant association with LOS. Significant preoperative variables included age, BMI, ASA class, smoking status, Charlson comorbidity index score ≥ 3, revision surgery, hemoglobin level, antidepressant use, and WCB claim. Significant operative variables were surgery group, intraoperative analgesics, operative time, and operating Surgeon 1. Postoperative transfusion also showed a statistically significant association with LOS. Both smoking status (RR = 0.69, 95% CI: [0.58, 0.82]) and WCB claim (RR = 0.63, 95% CI: [0.44, 0.92]) showed a slight negative association with LOS.

Factors that were not found to be statistically significantly associated with LOS upon bivariate analyses were female sex, preoperative narcotic use, preoperative neuroleptic use, both surgeons operating vs. only Surgeon 2, and intraoperative complications (dural tear or major complication vs. none).

5.3.1. Primary Findings: Multivariable Regression Analysis

We built a multivariable Poisson regression to look at the independent association of several factors with LOS. Results from the multivariable regression are summarized in Table 3. A total of 407 patients with full data were included in the model. Several of the variables from the bivariate analyses were no longer statistically significant in the multivariable analysis. After controlling for several factors, preoperative variables that were statistically significantly associated with longer LOS were age (RR = 1.02, 95% CI: [1.01, 1.03]), BMI (RR = 1.02, 95% CI: [1.01, 1.03]), and antidepressant use (RR = 1.16, 95% CI: [1.0, 1.35]). In terms of operative variables, compared to patients that underwent a discectomy, those who had a laminectomy stayed 1.8 times as long (95% CI: [1.16, 2.90]), 1-level TLIF stayed 2.8 times as long (95% CI: [1.76, 4.3]), 2-level TLIF stayed 2.6 times as long (95% CI: [1.61, 4.24]), and ALIF stayed 3.5 times as long (95% CI: [2.07, 5.84]). Patients that received long-acting analgesics (hydromorphone/morphine) intraoperatively stayed significantly longer compared to patients who received short acting analgesics (fentanyl/remifentanil) (RR = 1.35, 95% CI: [1.16, 1.58]). Operating surgeon was also significantly associated with LOS (Surgeon 1 vs. Surgeon 2 (RR = 0.86, 95% CI: [0.75, 0.98]); both Surgeons vs. Surgeon 2 (RR = 0.55, 95% CI: [0.36, 0.82])). As for postoperative factors, receiving a blood transfusion postoperatively was associated with a longer LOS (RR = 2.2, 95% CI: [1.62, 2.99]).

Factors that were not statistically significantly associated with LOS upon multivariable analysis were Charlson comorbidity index score ≥ 3 (RR = 1.26, 95% CI: [0.99, 1.61]), intraoperative dural tear (RR = 1.33, 95% CI: [0.9, 1.97]), major intraoperative complication (RR = 1.38, 95% CI: [0.82, 2.31]), female sex (RR = 1.0, 95% CI: [0.85, 1.18]), ASA class ≥ 3 (RR = 1.0, 95% CI: [0.86, 1.16]), revision surgery (RR = 1.15, 95% CI: [0.99, 1.33]), preoperative hemoglobin level (RR = 1.0, 95% CI: [0.99, 1.0]), preoperative narcotic use (RR = 1.08, 95% CI: [0.93, 1.25]), preoperative neuroleptic use (RR = 1.04, 95% CI: [0.9, 1.19]), WCB claim (RR = 1.02, 95% CI: [0.76, 1.36]), and smoking status (RR = 0.92, 95% CI: [0.80, 1.07]).

5.3.2. Secondary Findings: Stratified Surgical Models

To further explore the effect of surgery group on LOS, we performed stratified multivariable analyses for 1-level TLIF, discectomy, and laminectomy patients. The model for 1-level TLIFs included 171 patients with full data (9.5% were dropped due to missingness), discectomies included 89 patients with full data (28.2% were dropped due to missingness), and laminectomies included 81 patients with full data (10% were dropped due to missingness).

5.3.2.1. 1-level TLIF

In 1-level TLIF patients, both age (RR = 1.01, 95% CI: [1.0, 1.02]) and BMI (RR = 1.01, 95% CI: [1.0, 1.02]) remained statistically significantly associated with LOS. Charlson comorbidity index score ≥ 3 (RR = 1.38, 95% CI: [1.04, 1.84]) and preoperative narcotic use (RR = 1.24, 95% CI: [1.04, 1.47]) also had significant associations with LOS, which were not observed in the full population. Operating surgeon and preoperative antidepressant use no longer displayed statistical significance. Receiving long-acting analgesics intraoperatively compared to short-acting analgesics (RR = 1.26, 95% CI: [1.03, 1.54]), as well as receiving a blood transfusion postoperatively (RR = 2.95, 95% CI: [1.96, 4.42]), remained significantly associated with a longer LOS. Factors that were not found to be statistically significantly associated with LOS among 1-level TLIF patients were sex, ASA class ≥ 3, revision surgery, smoking status, preoperative hemoglobin level, preoperative neuroleptic use, preoperative antidepressant use, WCB claim, operating surgeon, intraoperative dural tear, and major complication.

5.3.2.2. Discectomy

In patients undergoing a discectomy, there were only two variables that had statistically significant associations with LOS: age (RR = 1.05, 95% CI: [1.01, 1.09]) and long- vs. short-acting intraoperative analgesics (RR = 5.36, 95% CI: [1.92, 14.96]). The statistically significant effects of BMI and preoperative antidepressants that were observed in the full population were not observed in discectomy patients. Factors that were not found to be statistically significantly associated with LOS among discectomy patients were female sex, BMI, ASA class ≥ 3, revision surgery, smoking status, preoperative hemoglobin level, preop narcotic use, preoperative neuroleptic use, preoperative antidepressant use, WCB claim, and intraoperative dural tear. No patients received a blood transfusion following discectomy surgery, and major intraoperative complication and operating surgeon were supressed due to small sample size.

5.3.2.3. Laminectomy

In patients undergoing a laminectomy, both age (RR = 1.04, 95% CI: [1.02, 1.07]) and BMI (RR = 1.05, 95% CI: [1.02, 1.08]) remained statistically significant, as did intraoperative analgesics (long-acting vs. short-acting) (RR = 1.46, 95% CI: [1.07, 2.01]) and postoperative blood transfusion (RR = 2.15, 95% CI: [1.30, 3.57]). WCB claim (RR = 2.16, 95% CI: [1.31, 3.54]) showed a statistically significant association with LOS, which was not observed in the full population or the other stratified models. Similarly, intraoperative dural tear (RR = 2.99, 95% CI: [1.95, 4.58]) was significantly associated with longer LOS, which was not observed in other models. Factors that were not found to be statistically significantly associated with LOS among

laminectomy patients were female sex, ASA class ≥ 3, revision surgery, smoking status, preoperative hemoglobin level, preoperative narcotic use, preoperative neuroleptic use, preoperative antidepressant use, operating surgeon, and major complication.

5.4. Multicollinearity

Our results did not suggest potential multicollinearity between ASA class and Charlson comorbidity index score. The bivariate correlation coefficient was below 0.7 ($R^2 = 0.23$) and the VIF was below 10 (mean VIF = 1.89). To further test potential collinearity, we removed Charlson comorbidity index score form the multivariable model and examined how the beta coefficient for ASA class changed. After removing Charlson comorbidity index score from the model, the coefficient for ASA class did not change significantly (2.5% increase), thus both variables were kept in the model.

Our results did not suggest major issues of multicollinearity between operative time and surgery group ($R^2 = 0.32$, mean VIF = 1.15), or operative time and intraoperative complications ($R^2 = 0.026$, mean VIF = 1.0). To further explore potential collinearity between operative time and surgery group, we removed operative time from the multivariable model and examined how the beta coefficients for surgery group changed. After removing operative time from the model, the coefficients for surgery group increased (1-level TLIF increased by 9.8%, 2-level TLIF by 17.2%, laminectomy by 0.6%, and ALIF by 9.8%), though not meaningfully (< 20%). Despite no statistically significant signs of multicollinearity between these variables, we decided not to include operative time in the final multivariable model, as we believed any major differences in operative time to be adequately captured by surgery group and intraoperative complication.

Other variables that were not included in the final multivariable model were the following: intraoperative transfusion, intraoperative analgesic dose, initial diagnosis, and narcotic dose. Intraoperative transfusion did not have sufficient power to include ($n < 5$), and we felt intraoperative analgesic dose was of secondary importance to the type of analgesia (short acting vs. long acting). It was decided *a priori* that surgery group would be included rather than initial diagnosis. Clinical diagnosis does not necessarily dictate type of surgery, and the surgical procedure performed is more likely to impact LOS than diagnosis. Preoperative narcotic dose was not included as we felt it was of secondary importance to whether or not the patient was prescribed narcotics at all, and it was not feasible at the time to convert the doses to equivalent units.

5.5. Sensitivity Analysis

A total of 15 patients had an initial diagnosis of degenerative scoliosis. Our final multivariable model included 14 of the 15 scoliotic patients (one patient was dropped due to missing data). When we excluded patients with a diagnosis of degenerative scoliosis and re-ran the multivariable analysis, all coefficients changed less than 12.7%.

Table 3. *Univariable and multivariable analysis, overall and stratified by surgery group.*

Variables	Bivariate	Multivariable			
		Full population	1-level TLIF	Discectomy	Laminectomy
	RR [95% CI]	RR [95% CI]	RR [95% CI]	RR [95% CI]	RR [95% CI]
Preoperative					
Sex (female)	1.09 [0.92, 1.3]	1.0 [0.85, 1.18]	1.18 [0.97, 1.42]	0.45 [0.19, 1.07]	0.81 [0.55, 1.19]
Age (years)	*1.03 [1.02, 1.04]	*1.02 [1.01, 1.03]	*1.01 [1.0, 1.02]	*1.05 [1.01, 1.09]	*1.04 [1.02, 1.07]
BMI (kg/m2)	*1.02 [1.11, 2.31]	*1.02 [1.01, 1.03]	*1.01 [1.0, 1.02]	0.98 [0.91, 1.06]	*1.05 [1.02, 1.08]
ASA class ≥ 3	*1.64 [1.37, 1.95]	1.0 [0.86, 1.16]	1.06 [0.88, 1.27]	0.42 [0.12, 1.42]	1.16 [0.78, 1.72]
Revision surgery	*1.48 [1.24, 1.75]	1.15 [0.99, 1.33]	1.03 [0.88, 1.21]	2.05 [0.89, 4.74]	1.29 [0.97, 1.71]
Smoking status	*0.69 [0.58, 0.82]	0.92 [0.80, 1.07]	0.90 [0.76, 1.07]	1.28 [0.51, 3.20]	0.82 [0.54, 1.23]
CCI score ≥ 3	*2.07 [1.50, 2.86]	1.26 [0.99, 1.61]	*1.38 [1.04, 1.84]	†	1.06 [0.59, 1.90]
Preoperative hemoglobin (g/L)	*0.98 [0.98, 0.99]	1.0 [0.99, 1.0]	1.0 [1.0, 1.01]	0.98 [0.95, 1.0]	1.0 [0.99, 1.01]
Preoperative narcotic use	1.11 [0.92, 1.33]	1.08 [0.93, 1.25]	*1.24 [1.04, 1.47]	1.14 [0.61, 2.14]	0.90 [0.62, 1.32]
Preoperative neuroleptic use	1.05 [0.88, 1.26]	1.04 [0.9, 1.19]	1.05 [0.90, 1.22]	1.09 [0.41, 2.91]	1.01 [0.74, 1.38]
Preoperative antidepressant use	*1.24 [1.05, 1.47]	*1.16 [1.0, 1.35]	1.10 [0.95, 1.28]	1.58 [0.71, 3.52]	1.29 [0.90, 1.85]
WCB claim	*0.63 [0.44, 0.92]	1.02 [0.76, 1.36]	0.88 [0.63, 1.22]	0.20 [0.01, 3.36]	*2.16 [1.31, 3.54]
Operative					
Surgery group					
Discectomy	Ref	Ref	Ref	Ref	Ref
Laminectomy	*3.18 [2.06, 4.93]	*1.83 [1.16, 2.90]	-	-	-
1-level TLIF	*5.07 [3.42, 7.53]	*2.75 [1.76, 4.3]	-	-	-
2-level TLIF	*5.71 [3.75, 8.68]	*2.62 [1.61, 4.24]	-	-	-
ALIF	*4.94 [3.09, 7.9]	*3.47 [2.07, 5.84]	-	-	-
Intraoperative analgesics					
Hydromorphone/ morphine (long acting)	*1.37 [1.12, 1.68]	*1.35 [1.16, 1.58]	*1.26 [1.03, 1.54]	*5.36 [1.92, 14.96]	*1.46 [1.07, 2.01]
Fentanyl/remifentanil (short acting)	Ref	Ref	Ref	Ref	Ref
Operative time (min)	*1.0 [1.0, 1.01]	-	-	-	-
Operating surgeon					
Surgeon 1	*0.61 [0.52, 0.73]	*0.86 [0.75, 0.98]	0.91 [0.78, 1.06]	0.53 [0.25, 1.15]	0.75 [0.53, 1.05]
Surgeon 2	Ref	Ref	Ref	Ref	Ref
Both	0.81 [0.52, 1.27]	*0.55 [0.36, 0.82]	0.90 [0.58, 1.38]	†	1.51 [0.26, 0.59]
Intraoperative complications					
Dural tear (minor)	1.31 [0.90, 1.91]	1.33 [0.9, 1.97]	0.83 [0.54, 1.27]	1.11 [0.40, 3.08]	*2.99 [1.95, 4.58]
Major	1.82 [0.92, 3.61]	1.38 [0.82, 2.31]	1.25 [0.99, 1.59]	†	1.51 [0.87, 2.61]
None	Ref	Ref	Ref	Ref	Ref
Postoperative					
Postoperative blood transfusion	*3.27 [2.13, 5.01]	*2.2 [1.62, 2.99]	*2.95 [1.96, 4.42]	†	*2.15 [1.30, 3.57]

* Indicates statistical significance ($P < 0.05$).
† Categories suppressed due to small sample size.
RR = risk ratio, CI = confidence interval, Ref = reference group, BMI = body mass index, ASA = American Society of Anesthesiology, CCI = Charlson comorbidity index, WCB = Workers' Compensation Board, TLIF = transforaminal lumbar interbody fusion, ALIF = anterior lumbar interbody fusion.

5.6. Data Quality

We calculated the percent agreement for four corresponding variables from another study at the institution that used an overlapping study population. Data for the variable revision surgery was abstracted in duplicate for 357 patients and the percent agreement between abstractors was 96.6%. Data for the variable surgical date (of which the outcome variable LOS was calculated) was abstracted in duplicate on 363 patients and the percent agreement between abstractors was 98.6%. Data for the variable operating surgeon was abstracted in duplicate on 309 patients and the percent agreement between abstractors was 99%. Data for the variable operative time was abstracted in duplicate on 362 patients and the percent agreement between abstractors was 95.3%.

Overall, missingness was not an issue in our data (see Table 2). Missingness was less than 5% for all variables except preoperative hemoglobin (6.5%) and Charlson comorbidity index score (6.3%). The biggest anticipated concern for missingness was with regard to comorbidity data. Missing data were imputed as zero (i.e. without the condition) for 29 patients with missing comorbidity data. The breakdown of this missingness can be found in Appendix G.

Chapter 6: Discussion/Conclusion

6.1. Objective 1: Descriptive

Half of all patients underwent TLIF (40% 1-level and 10.6% 2-level), while 26.2% underwent discectomy, and 19% laminectomy. In terms of individual health, a substantial proportion of the study population were taking medication preoperatively, including antidepressants (34.5%), neuroleptics (35%), and narcotics (28%), and 28.8% were smokers.

The median LOS for patients undergoing elective lumbar spine surgery for degenerative conditions was 3.0 days (IQR = 1-4). Only one other study in the literature reported on multiple surgical procedures combined (95). This study included 6,921 patients undergoing elective one- to three-level lumbar spine surgery for degenerative conditions for the first time, and just over 4% of the sample had a LOS $\geq$ 7 days (i.e. 'extended' LOS). In our study cohort, approximately 12% of patients stayed seven days or longer.

The median LOS for 1-level TLIF patients was 4.0 days (IQR = 3-6). This is slightly higher, but comparable to previous estimates. A study evaluating LOS in 103 patients who underwent elective, open, one- to three-level posterior lumbar fusion surgery reported a mean LOS of 3.6 days (SD = 1.8) (73). Interestingly, this estimate included two- and three-level fusions and is still shorter than the mean LOS in our sample of 1-level TLIFs (n = 189).

The median LOS for discectomy patients was 0 days (IQR = 0-1), and one-third of discectomy patients stayed one or more days in hospital postoperatively. The proportion of these patients with a 'long' LOS (as defined by a discharge after postoperative day zero according to Khechen et al. (114)) is considerably greater than previous estimates. In a recent study investigating risk factors for a long LOS after minimally invasive lumbar discectomy, 9.7% of patients (n = 17) stayed one or more days in hospital (114).

The median LOS for laminectomy patients was 2.0 days (IQR = 1-4). This is comparable to previous estimates. A study evaluating LOS in 2,358 patients undergoing lumbar laminectomy for spinal stenosis reported a mean LOS of 2.1 days (SD = 2.6 days) (67), and the Mayfield Clinic reports that laminectomy patients can expect to stay one to two days in hospital (66).

The result that approximately one-third of the study population was taking antidepressants is suggestive of an association between degenerative spine conditions (i.e. LBP) and clinical depression. This association has been established in the literature (115). These results are similar, though slightly higher, than some other estimates reported in the literature. For example, in a study looking at antidepressant use in 142 patients undergoing elective lumbar fusion surgery, 29% of patients were using antidepressants preoperatively (116). The proportion of patients taking narcotics preoperatively is actually lower than other estimates in spinal surgery. For example, a study on the long-term use of opioids after lumbar fusion surgery found that 15.9% of patients (n = 1331) did not use opioids prior to surgery (117).

6.2. Objective 2: Associations with Length of Stay

Factors that were statistically significantly associated with LOS following elective lumbar spine surgery for degenerative conditions in our adjusted model were age, BMI, preoperative antidepressant use, surgery group, long-acting intraoperative analgesics, operating surgeon, and postoperative blood transfusion. Surgery group had the strongest association with LOS, followed by postoperative blood transfusion, long-acting intraoperative analgesics, and intraoperative complications.

The statistical significance and magnitude of effect varied considerably for several factors upon stratification by 1-level TLIF, laminectomy, and discectomy, compared to the full population. This indicates underlying effect modification by surgery group. It is important to note that the sample sizes for the stratified surgical models are underpowered, thus we cannot draw definitive conclusions from them.

6.2.1. Individual Characteristics

Increasing age and BMI were statistically significantly associated with LOS after adjustment for other variables; however, their effect sizes were small (RR = 1.02, 95% CI: [1.01, 1.03] for both). These findings are not surprising as older age is often associated with greater comorbidities and a potentially greater postoperative complication rate (100). Obesity may be associated with higher rates of postoperative complications (118), particularly related to wound care and infection (119). Obesity may also interfere with rehabilitation protocols, leading to increased LOS. Other studies have consistently reported statically significant positive associations for both age (67,73,76,95,102) and BMI (67,76) with LOS after elective lumbar spine surgery.

6.2.2. Overall Health Status

Contrary to previous literature, having an ASA score of ≥ 3 (three indicates severe systemic disease) was not independently associated with a longer LOS, compared to an ASA score of one to two (healthy or mild systemic disease) (RR = 1.0, 95% CI: [0.86, 1.16]). The ASA Physical Status Classification System is used to assess patients' medical comorbidities prior to anesthesia (120). Based on results from previous literature in the field, we anticipated that ASA class would be a statistically significant independent predictor of longer LOS. Patients with severe systemic disease may be more likely to have perioperative complications that lead to a longer LOS. Several studies evaluating LOS after lumbar spine surgery found that patients with an ASA class ≥ 3 had a statistically significantly longer LOS, after controlling for other variables (67,73,76,95). The Charlson comorbidity index was also not statistically significantly associated with LOS; however, the effect size was larger compared to ASA (though still not considered a moderate sized effect). Compared to patients with a Charlson comorbidity index score of zero to two, patients with a Charlson comorbidity index score ≥ 3 stayed in hospital 1.26 times as long. Previous studies evaluating LOS after lumbar spine surgery have investigated individual comorbidities rather than a single index of comorbid status, and both diabetes (95,114) and heart disease (73) have been identified as independent risk factors for increased LOS. A study assessing the usefulness of the Charlson comorbidity index in elective spine surgery found that it

was not a good predictor of postoperative morbidity (121). The authors developed and validated a new spine surgery specific morbidity score to predict postoperative morbidity and mortality in elective spine surgery and found it had better predictability than the Charlson comorbidity index. The use of a spine specific comorbidity index may be more appropriate than the Charlson comorbidity index and ASA on their own for assessing the impact on LOS.

The effect of smoking showed a weak negative association with LOS and was not statistically significant (RR = 0.92, 95% CI: [0.80, 1.07]). Smoking status has not been identified as an independent risk factor for prolonged LOS after lumbar spine surgery in the literature. Nonetheless, we anticipated that smoking may prolong LOS due to various mechanisms such as increased risk of complication. One study evaluating LOS in patients undergoing lumbar fusion surgery reported the mean LOS for smokers (n = 19%) and non-smokers (81%) as 5.3 $\pm$ 2.4 days and 6.1 $\pm$ 2.4 days, respectively (102). A potential mechanism for the trend for shorter LOS among smokers observed in our study and others may be that patients who smoke are more motivated to be discharged early.

6.2.3. Preoperative Medication Use

The association between preoperative antidepressant use and LOS was statistically significant after controlling for other covariates; however, the effect size was weak (RR = 1.16, 95% CI: [1.0, 1.35]). This finding may suggest that poor mental health has a negative impact on surgical outcomes, including LOS. No other studies evaluating LOS after lumbar spine surgery have reported this association. Antidepressant use has also not commonly been considered in previous literature as it is not available in the large national databases used.

Preoperative narcotic and neuroleptic use showed weak and non-statistically significant associations with LOS (RR = 1.08, 95% CI: [0.93, 1.25] and RR = 1.04, 95% CI: [0.9, 1.19], respectively). Neuroleptics (also known as antipsychotics) are frequently used to calm nerve pain. We hypothesized that patients taking narcotics and neuroleptics preoperatively may require a longer hospital stay due to difficulties with postoperative pain management. One study actually found that preoperative narcotic use was associated with shorter LOS in patients undergoing minimally invasive TLIF and instrumentation (122). The same study also reported that preoperative oxycodone use was associated with a significantly longer LOS. The effect of neuroleptic use preoperatively on LOS has not been studied in the orthopedic spine literature, and literature in other surgical settings is sparse. A recent randomized controlled trial looked at perioperative pregabalin for reducing pain, analgesic use, and anxiety in elective neurosurgical patients and found no significant differences in LOS between the groups that used neuroleptics and those that did not (123).

6.2.4. Operative Considerations

A key finding was that surgical procedure was most strongly associated with LOS. Compared to discectomy patients, those that underwent a laminectomy stayed nearly two times as long (RR = 1.83, 95% CI: [1.16, 2.9]), and TLIF patients stayed over two times as long (1-level TLIF, RR = 2.75, 95% CI: [1.76, 4.3]; 2-level TLIF, RR = 2.62, 95% CI: [1.61, 4.24]). Patients that underwent an ALIF stayed three and half times as long compared to discectomy patients (RR =

3.47, 95% CI: [2.07, 5.84]). Underlying the decision to include all surgical procedures for degenerative lumbar spine conditions together was that these patients were likely similar enough in terms of how various factors would impact the outcome LOS. These results, including the moderate to strong effects of surgery group and the differences between the stratified models, suggest that the surgical populations/conditions may in fact be different in important ways (i.e. more heterogenous than we initially thought) and should be considered independently of one another.

Intraoperative analgesics and intraoperative complications had relatively weak positive associations with LOS (RR < 1.5) in the full population; however, they were amongst the strongest compared to other variables. Both variables showed strong positive effects (RR > 3) in the stratified models, including dural tear in laminectomy patients (RR = 2.99, 95% CI: [1.95, 4.58]) and long-acting intraoperative analgesics in discectomy patients (RR = 5.36, 95% CI: [1.92, 14.96]). Additionally, the effect of long-acting intraoperative analgesics compared to short-acting intraoperative analgesics was statistically significantly. Our study is the first known study to report the association between intraoperative analgesics and LOS in lumbar spine surgery. A similar study by Siemionow et al. (122) looked at several intraoperative anaesthetic considerations, including duration of anaesthesia, fluid balance, fentanyl, and midazolam, but did not specifically consider the effect of short vs. long acting intraoperative analgesia. In any case, intraoperative fentanyl was not a significant predictor of LOS. The effect of an intraoperative complication on LOS did not show statistical significance in the full population. Other than intraoperative transfusion, the impact of complications or adverse events during spine surgery on LOS and other outcomes has not been well studied.

Underlying the statistically significant association of operating surgeon and LOS in the full population is that certain procedures are more common in each of the surgeons. We found that Surgeon 1 performed 78% of all discectomies, which have the shortest average LOS out of all surgical procedures included. Compared to Surgeon 1, Surgeon 2 also performed 16% more 1-level TLIFs and 20% more 2-level TLIFs, which have the longest LOS out of all surgical procedures included. The purpose of including operating surgeon in the model was to control for any practice style differences.

6.2.5. Postoperative Considerations

Presence of a postoperative blood transfusion was the only postoperative factor included in the model. It showed a moderate (RR > 1.5) and positive statistically significant association with LOS. Patients that received a blood transfusion after surgery stayed 2.2 times as long compared to those who did not receive a blood transfusion. Gruskay et al. (73) found that anemia requiring a transfusion contributed significantly to patients staying in hospital longer after elective posterior lumbar fusion surgery. However, the authors did not include this variable in their multivariable regression due to its strong and potentially confounding relationship with LOS. It may also be that the presence of a postoperative blood transfusion is associated with increased blood loss during surgery, which in turn may be related to longer operative time (which has been shown to significantly impact LOS (76)). The direction of this association should be carefully considered, as it is also possible that a longer LOS is associated with an increased likelihood of requiring a blood transfusion.

6.3. Strengths

A key strength of this research is the representativeness of the study sample. We included consecutive spinal surgery patients at a single quaternary care centre in Nova Scotia. The two orthopedic spine surgeons included in this analysis perform nearly all orthopedic spine surgeries in Nova Scotia. Another strength of this research is the continuous LOS analysis, which allows for our findings to be interpreted based on varying definitions/opinions of what constitutes extended LOS or what is clinically meaningful. Considering LOS as a continuous variable also served to optimize the study power and allowed us to quantify the magnitude of effect for each independent variable and the LOS outcome.

Another strength of this research was the rigorous data abstraction process including 51 individual data pieces and 23 variables (13 preoperative, seven operative, two postoperative, and one outcome variable). This allowed us to investigate several covariates in addition to common ones (e.g. age, sex, BMI), including operating surgeon, preoperative medication use, and revision surgery. We also had high measures of percent agreement for four variables, suggesting good reliability of the data. The extensive database developed in the process of this research may be useful for addressing future research questions or quality improvement initiatives and is currently being explored by orthopedic residents within the department.

6.4. Limitations

A key limitation of this research is that we were limited to data available in patients' electronic medical charts due to the retrospective nature of the study. We did not include some important variables that have been shown to impact LOS in previous literature, such as discharge destination (e.g. nursing home or sub-acute care facility vs. home) (124) and availability of resources to support discharge, such as family (125) and community resources (126). Because these factors influence LOS, there are some biases in using LOS as a proxy for resource use. This information is not consistently and readily available in patients' electronic charts and thus was not included in the data abstraction. Perhaps some of this information could be obtained using data linkage; however, this would require further investigation and funding that was not feasible at this time. Another limitation of retrospective chart data is that it is primarily collected for clinical and administrative purposes and not for research.

For the 6% of patients with missing comorbidity data, it was assumed that there was no comorbidity present. This may be considered a limitation, as there is potential for selection bias to be introduced if patients with certain missing data are systematically different in some way. For example, perhaps patients with more complex health needs have longer medical charts and are thus not documented as comprehensively compared to healthier patients with more straightforward medical records. However, it is unlikely that this an issue that impacts the results in our study. Excluding patients with a LOS of 30 days or more may also introduce selection bias in our results. These patients (n = 4) were excluded not only because of their outlier status, but because their prolonged LOS was likely to due to reasons unrelated to surgery. However, it is still possible (though unlikely) that the LOS was related to surgery, such as the occurrence of a serious perioperative adverse event. Additionally, a LOS $\geq$ 30 days may be more common for certain surgical procedures, such as interbody fusions, which are more invasive compared to

other lumbar procedures included (e.g. discectomy and laminectomy). If that is the case, then LOS may appear shorter in this population. Additionally, if patients with a LOS ≥ 30 days are especially old and are excluded, then age may appear less associated with LOS in patients with lumbar interbody fusion.

Other limitations of this research relate to the data abstraction methods, such as potential errors in extracting and entering the data (127), which may lead to measurement bias. While there was a high level of agreement between two reviewers, there is still potential for errors and biases in the data. Studies consistently report concerns about drawing conclusions or making decisions based on retrospective chart reviews (128–131). One major concern pertains to issues with the quality of reporting. For example, practitioners may not carefully assess a patient's medical history, or they may not properly record what was done due to time restrictions (128,132,133).

The small sample sizes in the stratified models for 1-level TLIF, laminectomy, and discectomy is a limitation of this research, making it difficult to interpret and draw conclusions from the results. Almost all previous studies have focused on one specific surgical procedure (e.g. elective 1-level TLIF (76) or laminectomy (67)). Only one other study included all patients who underwent elective spine surgery for degenerative lumbar spine pathologies, including stenosis, spondylolisthesis, symptomatic mechanical disc collapse, and revision surgery (95).

6.5. Implications

The results from this research have important implications, especially for the local Orthopedic Spine division and future research. Our results contribute to the small, yet growing body of literature evaluating LOS in the surgical spine setting. Importantly, this was the first study to look at the factors associated with LOS after elective lumbar spine surgery in the Nova Scotian population. Previous findings could not be generalized to the local patient population; thus, this study was an imperative first step in order to conduct future confirmatory studies and build/test predictive models for LOS. The descriptive results in this study provide a better understanding of the demographic and clinical characteristics of the patient population undergoing elective lumbar spine surgery for degenerative conditions in Nova Scotia. We can also use this information to better understand how the Nova Scotian population compares to surgical spine populations in other regions across the globe. Ultimately, the results from this study provide many opportunities for future research and quality improvement.

6.5.1. Future Research

The objective of this research was exploratory in nature. We identified several prognostic factors and their association with the LOS outcome. Future confirmatory studies are needed to assess the prognostic value (or validity) of factors identified in initial exploratory studies such as this thesis. For example, a study looking at the prognostic value of ASA class as a predictor of extended LOS. Furthermore, the level of evidence from confirmatory research generally carries more weight than exploratory studies (134).

Future prospective research should also be conducted. Our study was limited to prognostic factors in the patients' medical charts due to the retrospective nature of the review. This included

missing data on important patient reported outcomes that should be considered in the context of the LOS outcome, such as pain and quality of life. Prospective research will allow for a more complete analysis of independent variables, including potential confounders and other prognostic factors that have been identified in previous studies that are not readily available in the electronic medical chart. It will also allow for the prospective collection of patient-reported outcome variables at various postoperative follow up periods. See Section 6.5.2.1.for specific variable recommendations.

Future research should also include the development and testing of a predictive model for LOS that is sensitive and specific. This will allow administrators to accurately predict a patients likely LOS and appropriately schedule and manage resources accordingly to improve hospital efficiency. Knowing approximately how long a patient is likely to stay in hospital following elective spine surgery may also inform individual care. In addition to data-driven variable selection approaches, results from the theory-driven explanatory model in this study may help to inform which prognostic factors to include in a predication model to best assess the outcome LOS. Future predictive models should include the largest sample sizes available in order to predict the outcome with maximum precision and to allow for the use of training and validation datasets.

Our results varied considerably for the surgery specific multivariable models, indicating effect modification by surgery group. Thus, we strongly recommend that future research considers more homogenous patient populations, such as limited to a single surgical procedure (e.g. 1-level TLIF) or clinical condition (e.g. disc herniation) and includes larger sample sizes.

The prevalence of preoperative antidepressant use among patients in our study was noteworthy, with over one-third of the sample taking antidepressants at the time of surgery. Preoperative antidepressant use was also statistically significantly associated with longer LOS ($p = 0.039$). Clinicians should be aware of the high prevalence of mental health issues in this population and the potential that it could negatively impact LOS. Future research should be conducted to confirm this association. If it is true that poor mental health negatively impacts postsurgical outcomes (i.e. LOS) and that there is a high prevalence of mental health concerns in this population, then there should be a focus on appropriate psychology/psychiatry support services perioperatively.

6.5.2. Quality Improvement and Learning Health Systems

This research has the potential to contribute to quality improvement and learning health systems within the Orthopedic Spine division. Learning health systems combine health and research systems to enable continuous learning and improvement cycles with the key aim of improving health system performance at a lower cost (135,136). These learning cycles have three phases: 1) Practice to Data, 2) Data to Knowledge, and 3) Knowledge to Practice. The first phase focuses on generating and managing clinical data. Engaging clinicians and/or patients in this phase is key to good data management. The second phase involves the translation of data to knowledge in order to influence decision making and improvements in the learning health system. In the third phase, knowledge is applied to guide decision making, improve practice, and ultimately improve the value of care (136). In order to improve care and support continuous learning, there should be

a principal focus on the way data are collected, used, and shared within the Orthopedic Spine division in the future. Through this research we were able identify important gaps/limitations in the Practice to Data phase and make recommendations to guide new data collection and improve future research (Data to Knowledge phase).

Firstly, we recommend that data be collected prospectively. The retrospective review process is time intensive and may increase errors in the data abstraction process. It may also be beneficial to consider the use of a secure web-based software for housing the data, such as REDCap (Research Electronic Data CAPture) to support data security and quality. Infrastructure that allows high-quality clinical data to be collected, analyzed, and applied is central to the ability of learning health systems to promote learning as a result of routine care (136). Lastly, we recommend the modification of several preoperative, operative, and postoperative variables and the addition of others.

6.5.2.1. Variables to collect in valid, reliable way

6.5.2.1.1. Preoperative

Use of narcotics preoperatively was recorded for oxycodone, morphine, hydromorphone, fentanyl, and methadone, as well as the prescribed doses. In the future, the narcotic doses should be converted to morphine equivalents using published guidelines, such as those reported by the Michael G. Degroote National Pain Centre, McMaster University (137).

The most comprehensive and time intensive measure we collected was the Charlson comorbidity index, which included data on 19 clinical conditions. It would be wise to look further into the predictive validity of the Charlson comorbidity index for future research, specifically with regard to the surgical spine population. Perhaps there are other variable that capture comorbidity/health state that require fewer resources to collect (e.g. ASA class). Furthermore, presence of renal disease (which is included in the Charlson comorbidity index) was abstracted from the anesthesia report; however, deciding on a clinical cutoff and assessing a patient's creatinine levels immediately preoperatively may provide a more accurate depiction of renal comorbidity.

Preoperative factors that should be considered in future research include social factors or measures of socioeconomic status (e.g. employment status, education level), and at-home supports (e.g. marital status, living arrangements).

6.5.2.1.2 Operative

The variable surgery group should be refined to identify surgeries which include more than one procedure. The primary procedure should be noted, as well as any secondary procedures performed. For example, 'fusion with decompression' or 'discectomy and decompression'. In addition, the approach used (e.g. minimally invasive vs. open, or midline vs. paramedian) should be recorded as these distinctions can impact LOS.

Intraoperative adverse events should be coded using the Spinal AdVerse Events System (SAVES) for categorizing and classifying adverse events in spine surgery. This will provide more standardized adverse event data and allow for comparison of results between studies.

Blood loss was not consistently reported and was missing in a significant proportion of charts. It is well established in the literature that visually estimated blood loss is not the most accurate measure (112,113). It would be of interest to investigate whether or not other variables adequately capture the underlying concept of intraoperative blood loss, such as pre- and post-operative hemoglobin, operative time, or surgical procedure.

6.5.2.1.3. Postoperative

An acceptable date range for the collection of postoperative hemoglobin and transfusion should be established (e.g. within three days of the surgical date) and the date recorded. This will help to standardize these estimates.

Postoperative factors that should be considered in future research include patient reported outcomes (quality of life, pain), postoperative analgesics (narcotics, neuroleptics), postoperative complications (including date and grade), discharge destination (home with support vs. no support, nursing home, rehabilitation center, hospital transfer), and reoperation within one year. Additionally, the abstractor who recorded the data for each patient should be documented to allow for measures of reliability within and between abstractors.

6.8. Conclusions

We found several factors to be associated with LOS, which provide preliminary evidence for the development of robust predictive models for LOS. Our results showed that LOS is highly procedure specific, thus future research should focus on more homogenous populations, such as limited to a single surgical procedure or clinical diagnosis. We also recommend the need for future prospective and confirmatory prognostic studies.

References

1. Ravindra VM, Senglaub SS, Rattani A, Dewan MC, Härtl R, Bisson E, et al. Degenerative Lumbar Spine Disease: Estimating Global Incidence and Worldwide Volume. Glob Spine J. 2018;8(8):784–94.
2. Kassebaum NJ, Arora M, Barber RM, Brown J, Carter A, Casey DC, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 315 diseases and injuries and healthy life expectancy (HALE), 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1603–58.
3. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, et al. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012;64(6):2028–37.
4. Gross DP, Ferrari R, Russell AS, Battié MC, Schopflocher D, Hu RW, et al. A population-based survey of back pain beliefs in Canada. Spine (Phila Pa 1976). 2006;31(18):2142–5.
5. Airaksinen O, Brox JI, Cedraschi C, Hildebrandt J, Klaber-Moffett J, Kovacs F, et al. Chapter 4: European guidelines for the management of chronic nonspecific low back pain. Eur Spine J. 2006;15(SUPPL. 2):192–300.
6. Adogwa O, Lilly DT, Khalid S, Desai SA, Vuong VD, Davison MA, et al. Extended Length of Stay After Lumbar Spine Surgery: Sick Patients, Postoperative Complications, or Practice Style Differences Among Hospitals and Physicians? World Neurosurg. 2018;734–9.
7. Du Bois M, Szpalski M, Donceel P. A decade's experience in lumbar spine surgery in Belgium: Sickness fund beneficiaries, 2000-2009. Eur Spine J. 2012;21(12):2693–703.
8. Bernstein DN, Brodell D, Li Y, Rubery PT, Mesfin A. Impact of the economic downturn on elective lumbar spine surgery in the United States: A national trend analysis, 2003 to 2013. Glob Spine J. 2017;7(3):213–9.
9. Aghajani S, Kargari M. Determining Factors Influencing Length of Stay and Predicting Length of Stay Using Data Mining in the General Surgery Department. Hosp Pract Res [Internet]. 2016;1(2):51–6.
10. Yeom JS, Buchowski JM, Shen HX, Liu G, Bunmaprasert T, Riew KD. Effect of fibrin sealant on drain output and duration of hospitalization after multilevel anterior cervical fusion: A retrospective matched pair analysis. Spine (Phila Pa 1976). 2008;33(16).
11. Organization for Economic Cooperation and Development. 9. Health Care Activities. In: Health at a Glance. 2017. p. 176–7.
12. Health Catalyst. Patient-Centered LOS Reduction Initiative Improves Outcomes, Lowers Costs [Internet]. 2017. p. 1–11. Available from: https://www.healthcatalyst.com/wp-content/uploads/2016/06/Patient-Centered-LOS-Reduction-Initiative-Improves-Outcomes-Lowers-Costs.pdf
13. Beaumont Health. Common Orthopedic Injuries [Internet]. [cited 2019 Aug 19]. Available from: https://www.beaumont.org/conditions/common-orthopedic-injuries
14. Woolf AD, Pfleger B. Burden of major musculoskeletal conditions. 2010;81(03).

15. Badley E, Rasooly I, Webster G. Relative importance of musculoskeletal disorders as a cause of chronic health problems, disability, and health care utilization: findings from the 1990 Ontario Health Survey. J Rheumatol. 1994;21:505–14.

16. The Conference Board of Canada. Mortality Due to Musculoskeletal System Diseases [Internet]. 2012 [cited 2019 Aug 19]. Available from: https://www.conferenceboard.ca/hcp/Details/Health/mortality-musculoskeletal-system.aspx?AspxAutoDetectCookieSupport=1

17. Hurwitz EL, Randhawa K, Yu H, Côté P, Haldeman S. The Global Spine Care Initiative: a summary of the global burden of low back and neck pain studies. Eur Spine J. 2018;27(s6):796–801.

18. Vos T, Allen C, Arora M, Barber RM, Brown A, Carter A, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1545–602.

19. Buchbinder R, van Tulder M, Öberg B, Costa LM, Woolf A, Schoene M, et al. Low back pain: a call for action. Lancet. 2018;391(10137):2384–8.

20. Hoy D, March L, Brooks P, Woolf A, Blyth F, Vos T, et al. Measuring the global burden of low back pain. Best Pract Res Clin Rheumatol. 2010;24(2):155–65.

21. Hoy D, March L, Brooks P, Blyth F, Woolf A, Bain C, et al. The global burden of low back pain: Estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis. 2014;73(6):968–74.

22. Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. Spine J. 2008;8(1):8–20.

23. Schofield DJ, Shrestha RN, Passey ME, Earnest A, Fletcher SL. Chronic disease and labour force participation among older Australians. Med community. 2008;189(8):447–50.

24. Schofield DJ, Shrestha RN, Percival R, Callander EJ, Kelly SJ, Passey ME. Early retirement and the financial assets of individuals with back problems. Eur Spine J. 2011;20(5):731–6.

25. Foster NE, Anema JR, Cherkin D, Chou R, Cohen SP, Gross DP, et al. Prevention and treatment of low back pain: evidence, challenges, and promising directions. Lancet. 2018;391(10137):2368–83.

26. Hoy D, Brooks P, Blyth F, Buchbinder R. The Epidemiology of low back pain. Best Pract Res Clin Rheumatol. 2010;24(6):769–81.

27. Ardakani EM, Leboeuf-Yde C, Walker BF. Failure to define low back pain as a disease or an episode renders research on causality unsuitable: Results of a systematic review. Chiropr Man Ther. 2018;26(1):1–10.

28. Koes B, van Tulder M, Thomas S. Diagnosis and treatment of low back pain. BMJ. 2006;332:1430–34.

29. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira ML, Genevay S, et al. What low back pain is and why we need to pay attention. Lancet. 2018;391(10137):2356–67.

30. Maher C, Underwood M, Buchbinder R. Non-specific low back pain. Lancet. 2017;389(10070):736–47.

31. Fisher C, Hall H, Love L, Manson N, Mcintosh G, Rampersaud R, et al. Canadian Spine Outcomes 2017 Annual Report. 2017.

32. Evans N, Mccarthy M. Management of symptomatic degenerative low-grade lumbar spondylolisthesis. 2018;3(December).

33. Deng M, Xiang Y, Wang J, Leung JCS. Lumbar degenerative spondylolisthesis epidemiology : A systematic review with a focus on gender-specific and age-specific prevalence. J Orthop Transl. 2017;11:39–52.

34. Ullrich P. Isthmic Spondylolisthesis [Internet]. Spine Health. 2011 [cited 2019 Oct 19]. Available from: https://www.spine-health.com/conditions/spondylolisthesis/isthmic-spondylolisthesis

35. Genevaya S, Atlas SJ. Lumbar Spinal Stenosis. Best Pract Res Clin Rheumatol. 2010;24:253–65.

36. Moon MS, Kim SS, Sihn JC. Lumbar spinal stenosis - a current view. Orthop Trauma. 2014;28(6):396–408.

37. Melancia JL, Francisco AF, Antunes JL. Spinal stenosis. Handb Clin Neurol [Internet]. 2014 Jan 1 [cited 2019 Aug 20];119:541–9. Available from: https://www.sciencedirect.com/science/article/pii/B9780702040863000357

38. Lurie J, Tomkins-Lane C. Management of lumbar spinal stenosis. BMJ. 2016;352:H6234.

39. Deyo RA. Treatment of lumbar spinal stenosis: a balancing act. Spine J. 2010;10(7):625–7.

40. Chen E, Tong KB, Laouri M. Surgical treatment patterns among Medicare beneficiaries newly diagnosed with lumbar spinal stenosis. Spine J. 2010;10(7):588–94.

41. Andersen T, Christensen FB, Langdahl BL, Ernst C, Fruensgaard S, Østergaard J, et al. Degenerative Spondylolisthesis Is Associated with Low Spinal Bone Density : A Comparative Study between Spinal Stenosis and Degenerative Spondylolisthesis. Biomed Res Int. 2013;1–8.

42. American Association of Neurological Surgeons. Herniated Disc [Internet]. [cited 2019 Aug 22]. Available from: https://www.aans.org/en/Patients/Neurosurgical-Conditions-and-Treatments/Herniated-Disc

43. Jordan J, Konstantinou K. Herniated lumbar disc. Clin Evid (Online). 2009;3(June):1–34.

44. Dulebohn SC, Massa RN, Mesfin FB. Disc Herniation. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2019. Available from: https://www.ncbi.nlm.nih.gov/books/NBK441822/?report=classic

45. Battié MC, Videman T, Parent E. Lumbar disc degeneration: Epidemiology and genetic influences. Spine (Phila Pa 1976). 2004;29(23):2679–90.

46. Delgado-López PD, Rodríguez-Salazar A, Martín-Alonso J, Martín-Velasco V. Lumbar disc herniation: Natural history, role of physical examination, timing of surgery, treatment options and conflicts of interests. Neurocirugia. 2017;28(3):124–34.

47. Wong JJ, Côté P, Quesnele JJ, Stern PJ, Mior SA. The course and prognostic factors of symptomatic cervical disc herniation with radiculopathy: A systematic review of the literature. Spine J. 2014;14(8):1781–9.

48. Rosenberg JJ. Scoliosis. Pediatr Rev [Internet]. 2011;32(9):397–8. Available from: https://pedsinreview.aappublications.org/content/32/9/397.long

49. Silva FE, Lenke LG. Adult degenerative scoliosis: Evaluation and management. Neurosurg Focus. 2010;28(3):1–10.

50. Carter OD, Haynes SG. Prevalence rates for scoliosis in US adults: Results from the first national health and nutrition examination survey. Int J Epidemiol. 1987;16(4):537–44.

51. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, et al. Adult scoliosis: Prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine (Phila Pa 1976). 2005;30(9):1082–5.

52. Matz PG, Meagher RJ, Lamer T, Tontz WL, Annaswamy TM, Cassidy RC, et al. Guideline summary review: An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2016;16(3):439–48.

53. McIntosh G, Hall H, Melles T. The Incidence of Spinal Surgery in Canada. Can J Surg. 1998;41(1):59–66.

54. Rajaee SS, Bae HW, Kanim LEA, Delamarter RB. Spinal Fusion in the United States. Spine (Phila Pa 1976). 2011;37(1):67–76.

55. Goz V, Weinreb JH, Mccarthy I, Schwab F, Lafage V, Errico TJ. Perioperative Complications and Mortality. 2013;38(22):1970–6.

56. Bederman S, Kreder HJ, Weller I, Finkelstein JA, Ford MH, Yee AJM. The who, what and when of surgery for the degenerative lumbar spine: A population-based study of surgeon factors, surgical procedures, recent trends and reoperation rates. Can J Surg. 2009;52(4):283–90.

57. Deyo RA , Mirza SK , Martin BI et al. Trends, major medical complications, and charges associated with surgery for lumbar spinal stenosis in older adults. Jama 2010. 2010;303(13):1259 – 65.

58. Glennie A. Personal Communication. 2014.

59. Deyo RA , Mirza SK , Martin BI et al. Trends, major medical com- plications, and charges associated with surgery for lumbar spinal stenosis in older adults. Jama 2010. 2010;303(13):1259 – 65.

60. Oxner W. Personal Communication.

61. Ontario Ministry of Health and Long-Term Care. Quality-Based Pathway: Clinical Handbook for Non-Emergent Integrated Spine Care. 2017.

62. Healthwise. Discectomy or Microdiscectomy for a Lumbar Herniated Disc [Internet]. 2017 [cited 2019 Sep 6]. Available from: https://www.healthlinkbc.ca/health-topics/hw218424

63. Sørlie A, Gulati S, Giannadakis C, Carlsen SM, Salvesen Ø, Nygaard ØP, et al. Open discectomy vs microdiscectomy for lumbar disc herniation - a protocol for a pragmatic comparative effectiveness study. F1000Research. 2016;5(0):1–10.

64. Mayfield Brain and Spine. Lumbar Discectomy [Internet]. 2018 [cited 2019 Sep 6]. Available from: https://mayfieldclinic.com/pe-lumdiscectomy.htm

65. Mayo Clinic. Laminectomy [Internet]. 2018 [cited 2019 Sep 5]. Available from: https://www.mayoclinic.org/tests-procedures/laminectomy/about/pac-20394533

66. Mayfield Brain and Spine. Spinal Decompression (laminectomy) [Internet]. Mayfield Clinic. 2018 [cited 2019 Sep 5]. Available from: https://mayfieldclinic.com/pe-decompression.htm

67. Basques BA, Varthi AG, Golinvaux NS, Bohl DD, Grauer JN. Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis. Spine (Phila Pa 1976). 2014;39(10):833–40.

68. The Ottawa Hospital. Lumbar Spine Decompression With and Without Fusion [Internet]. 2013. Available from: https://www.ottawahospital.on.ca/en/documents/2017/01/lumbar-spine-decompression-with-and-without-fusion.pdf/

69. Mayfield Brain and Spine. Preparing for Lumbar Spinal Fusion [Internet]. 2018 [cited 2019 Sep 8]. Available from: https://mayfieldclinic.com/pe-fusionpreparing.htm

70. Mayfield Brain and Spine. Spinal Fractures [Internet]. Mayfield Clinic. 2018 [cited 2019 Aug 29]. Available from: https://mayfieldclinic.com/pe-spinefract.htm

71. Patient Education Committee. Spinal Fusion [Internet]. North American Spine Society. [cited 2019 Sep 9]. Available from: https://www.spine.org/KnowYourBack/Treatments/Surgical-Options/Spinal-Fusion

72. Lee N, Kim KN, Yi S, Ha Y, Shin DA, Yoon DH, et al. Comparison of Outcomes of Anterior, Posterior, and Transforaminal Lumbar Interbody Fusion Surgery at a Single Lumbar Level with Degenerative Spinal Disease. World Neurosurg. 2017;216–26.

73. Gruskay JA, Fu M, Bohl DD, Webb ML, Grauer JN. Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis. Spine J. 2015;15(6):1188–95.

74. Montgomery SP. Transforaminal Lumbar Interbody Fusion (TLIF) Back Surgery [Internet]. Spine Health. 2003 [cited 2019 Sep 9]. Available from: https://www.spine-health.com/treatment/spinal-fusion/transforaminal-lumbar-interbody-fusion-tlif-back-surgery

75. Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. Spine (Phila Pa 1976). 2012;37(22):1914–9.

76. Basques BA, Fu MC, Buerba RA, Bohl DD, Golinvaux NS, Grauer JN. Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion. Spine (Phila Pa 1976). 2014;39(6):497–502.

77. Sasso RC, Best NM, Mummaneni P V., Reilly TM, Hussain SM. Analysis of operative complications in a series of 471 anterior lumbar interbody fusion procedures. Spine (Phila Pa 1976). 2005;30(6):670–4.

78. Proietti L, Scaramuzzo L, Schiro' GR, Sessa S, Logroscino CA. Complications in lumbar spine surgery: A retrospective analysis. 2013;47(4):340–5.

79. Collins TC, Daley J, Henderson WH, Khuri SF. Risk factors for prolonged length of stay after major elective surgery. Ann Surg. 1999;230(2):251–9.

80. Devine J, Norvell DC, Ecker E, Fourney DR, Vaccaro A, Wang J, et al. Evaluating the correlation and responsiveness of patient-reported pain with function and quality-of-life outcomes after spine surgery. Spine (Phila Pa 1976). 2011;36(21 SUPPL.):69–74.

81. Eapen ZJ, Reed SD, Li Y, Kociol RD, Armstrong PW, Starling RC, et al. Do countries or hospitals with longer hospital stays for acute heart failure have lower readmission rates? Findings from ASCEND-HF. Circ Hear Fail. 2013;6(4):727–32.

82. Southern WN, Arnsten JH. Increased Risk of Mortality among Patients Cared for by Physicians with Short Length-of-Stay Tendencies. J Gen Intern Med. 2015;30(6):712–8.

83. Vogt MT, Kwoh CK, Cope DK, Osial TA, Culyba M, Starz TW. Analgesic usage for low back pain: Impact on health care costs and service use. Spine (Phila Pa 1976). 2005;30(9):1075–81.

84. Glennie R, Barry S, Alant J, Christie S, Oxner W. Will cost transparency in the operating theatre cause surgeons to change their practice? J Clin Neurosci. 2019;60:1–6.

85. Boakye M, Zygourakis CC, Kalanithi PSA, Lad SP, Arrigo RT, Gephart MGH. Venous Thromboembolism After Thoracic/Thoracolumbar Spinal Fusion. World Neurosurg [Internet]. 2011;78(5):545–52. Available from: http://dx.doi.org/10.1016/j.wneu.2011.12.089

86. Baker GR, Norton PG, Flintoft V, Blais R, Brown A, Cox J, et al. The Canadian Adverse Events Study: The incidence of adverse events among hospital patients in Canada. Cmaj. 2004;170(11):1678–86.

87. Vonlanthen R, Slankamenac K, Breitenstein S, Puhan MA, Muller MK, Hahnloser D, et al. The impact of complications on costs of major surgical procedures: A cost analysis of 1200 patients. Ann Surg. 2011;254(6):907–13.

88. Marshall AH, McClean SI, Shapcott CM, Millard PH. Modelling patient duration of stay to facilitate resource management of geriatric hospitals. Health Care Manag Sci. 2002;5(4):313–9.

89. Krell RW, Girotti ME, Dimick JB. Extended length of stay after surgery: complications, inefficient practice, or sick patients? 2014;154(11):2262–5.

90. Kanaan SF, Waitman LR, Yeh H-W, Arnold PM, Burton DC, Sharma NK. Structural equation model analysis of the length-of-hospital stay after lumbar spine surgery. Spine J. 2015;15(4):612–21.

91. Jack W. October 1999 [Internet]. Principles of Health Economics for Developing Countries. World Bank Publications; 1999. Available from: http://archderm.ama-assn.org/cgi/doi/10.1001/archderm.135.10.1286

92. Basques BA, Fu MC, Buerba RA, Bohl DD, Golinvaux NS, Grauer JN. Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion. Spine (Phila Pa 1976) [Internet]. 2014;39(6):497–502.

93. Basques BA, Bohl DD, Golinvaux NS, Gruskay JA, Grauer JN. Preoperative factors affecting length of stay after elective ACDF with and without corpectomy: a multivariate analysis of an academic center cohort. Spine (Phila Pa 1976). 2014;39(12):939–46.

94. Siemionow K, Pelton M a., Hoskins J a., Singh K. Predictive Factors of Hospital Stay in Patients Undergoing Minimally Invasive Transforaminal Lumbar Interbody Fusion and Instrumentation. Spine (Phila Pa 1976). 2012;37(24):1.

95. McGirt MJ, Parker SL, Chotai S, Pfortmiller D, Sorenson JM, Foley K, et al. Predictors of extended length of stay, discharge to inpatient rehab, and hospital readmission following elective lumbar spine surgery: introduction of the Carolina-Semmes Grading Scale. J Neurosurg Spine [Internet]. 2017;27(4):382–90.

96. Bennette C, Vickers A. Against quantiles: categorization of continuous variables in epidemiologic research, and its discontents. BMC Med Res Methodol. 2012;12(21).

97. Gruskay JA, Fu M, Bohl DD, Webb ML, Grauer JN. Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis. Spine J. 2015;15(6):1188–95.

98. Basques BA, Varthi AG, Golinvaux NS, Bohl DD, Grauer JN. Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis. Spine (Phila Pa 1976) [Internet]. 2014;39(10):833–40.

99. Basques BA, Fu MC, Buerba RA, Bohl DD, Golinvaux NS, Grauer JN. Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion. Spine (Phila Pa 1976). 2014;39(6):497–502.

100. Zheng F, Cammisa FP, Sandhu HS, Girardi FP, Khan SN. Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation. Spine (Phila Pa 1976). 2002;27(8):818–24.

101. Siemionow K, Pelton MA, Hoskins JA, Singh K. Predictive factors of hospital stay in patients undergoing minimally invasive transforaminal lumbar interbody fusion and instrumentation. Spine (Phila Pa 1976). 2012;37(24):2046–54.

102. Zheng F, Cammisa FP, Sandhu HS, Girardi FP, Khan SN. Factors Predicting Hospital Stay, Operative Time, Blood Loss, and Transfusion in Patients Undergoing Revision Posterior Lumbar Spine Decompression, Fusion, and Segmental Instrumentation. Spine (Phila Pa 1976). 2002;27(8):818–24.

103. Stevens M, Moreside J, Dunning C, Oxner B, Glennie A. Factors Predicting Length of Stay After Elective Lumbar Spine Surgery Leading to the Development of Personalized Clinical Care Pathways. Dalhousie University; 2018.

104. Harrells F. What are some of the problems with stepwise regression? [Internet]. STATA. Available from: https://www.stata.com/support/faqs/statistics/stepwise-regression-problems/

105. Microsoft Corperation. Microsoft Excel. 2017.

106. Vassar M, Holzmann M. The retrospective chart review: important methodological considerations. J Educ Eval Health Prof. 2013;10:12.

107. Owens WD, Felts JA, Spitznagel EL. ASA Physical Status Classifications: A study of Consistency of Ratings. Anaesthesiology. 1978;49(4):239–43.

108. Quan H, Li B, Couris CM, Fushimi K, Graham P, Hider P, et al. Updating and validating the charlson comorbidity index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. Am J Epidemiol. 2011;173(6):676–82.

109. Roffman CE, Buchanan J, Allison GT. Predictors of non-use of prostheses by people with lower limb amputation after discharge from rehabilitation: Development and validation of clinical prediction rules. J Physiother. 2014;60(4):224–31.

110. Szubski CR, Tellez A, Klika AK, Xu M, Kattan MW, Jorge A. Review of long-Term Care Hospital Classification– Asheville Specialty Hospital. 2014.

111. StataCorp. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC; 2017.

112. Algadiem EA, Aleisa AA, Alsubaie HI, Buhlaiqah NR, Algadeeb JB, Alsneini HA, et al. Blood Loss Estimation Using Gauze Visual Analogue. J trauma Emerg Med. 2016;21(2):1–4.

113. Schorn MN. Measurement of Blood Loss: Review of the Literature. J Midwifery Womens Health. 2010;55(1):20–7.

114. Khechen B, Haws BE, Patel D V., Narain AS, Hijji FY, Bawa MS, et al. Risk Factors for a Long Hospital Stay Following Minimally Invasive Lumbar Discectomy. Clin Spine Surg. 2019;32(1):E56–9.

115. Geisser ME, Roth RS, Robinson ME. Assessing Depression among Persons with Chronic Pain Using the Center for Epidemiological Studies-Depression Scale and the Beck Depression Inventory: A Comparative Analysis. Clin J Pain. 1997;13(2):163–70.

116. Sayadipour A, Kepler CK, Mago R, Certa KM, Rasouli MR, Vaccaro AR, et al. Economic Effects of Anti-Depressant Usage on Elective Lumbar Fusion Surgery. Arch Bone Jt Surg. 2016;4(3):231–5.

117. Connolly J, Javed Z, Raji MA, Chan W, Kuo YF, Baillargeon J. Predictors of Long-term Opioid Use Following Lumbar Fusion Surgery. Spine (Phila Pa 1976). 2017;42(18):1405–11.

118. Kalanithi P, Arrigo R, Boakye M. Morbid obesity increases cost and complication rates in spinal arthrodesis. Spine (Phila Pa 1976). 2012;37:982–8.

119. Houdek MT, Griffin AM, Ferguson PC WJ. Morbid Obesity Increases the Risk of Postoperative Wound Complications, Infection, and Repeat Surgical Procedures Following Upper Extremity Limb Salvage Surgery for Soft Tissue Sarcoma. Hand. 2019;1(14).

120. ASA House of Delegates/Executive Committee. ASA Physical Status Classification System [Internet]. 2019. Available from: https://www.asahq.org/standards-and-guidelines/asa-physical-status-classification-system

121. Manu A, Shetty AP, Shanmughanathan R, Kanna RM. A Validated New Spine Surgery Specific Morbidity Score to Predict Postoperative Morbidity and Mortality in Elective Spine Surgery. Spine (Phila Pa 1976). 2011.

122. Siemionow K, Pelton M, Hoskins J, Singh K. Predictive Factors of Hospital Stay in Patients Undergoing Minimally Invasive Transforaminal Lumbar Interbody Fusion and Instrumentation. Spine (Phila Pa 1976). 2012;37(24).

123. Shimony N, Amit U, Minz B, Grossman R, Dany MA, Gonen L, et al. Perioperative pregabalin for reducing pain, analgesic consumption, and anxiety and enhancing sleep quality in elective neurosurgical patients: A prospective, randomized, double-blind, and controlled clinical study. J Neurosurg. 2016;125(6):1513–22.

124. Gruskay JA, Fu M, Basques BA, Bohl DD, Buerba RA, Webb ML, et al. Factors Affecting Length of Stay and Complications After Elective Anterior Cervical Discectomy and Fusion. Clin spine Surg. 2016;29(1):34–42.

125. Shelton W, Moore CD, Socaris S, Gao J, Dowling J. The effect of a family support intervention on family satisfaction, length-of-stay, and cost of care in the intensive care unit. Crit Care Med. 2010;38(5):1315–20.

126. Systema S, Burgess P, Tansella M. Does Community Care Decrease Length of Stay and Risk of Rehospitalization in New Patients With Schizophrenia Disorders? A Comparative Case Register Study in Groningen, the Netherlands; Victoria, Australia; and South Verona, Italy. Schizophr Bull. 2012;28(2):273–81.

127. Hershey CO, Karuza J. Assessment of preventive health care: Design considerations. Prev Med (Baltim). 1997;26(1):59–67.

128. J. L, J.W. P, T.R. D, M. L, P. G. How well does chart abstraction measure quality? A prospective comparison of standardized patients with the medical record. Am J Med. 2000;108(8):642–9.

129. Norman GR, Neufeld VR, Walsh A, Woodward CA, McConvey GA. Measuring physicians' performances by using simulated patients. Vol. 60, J Med Educ. 1985. p. 925–34.

130. Rethans JJ, Martin E, Metsemakers J. To what extent do clinical notes by general practitioners reflect actual medical performance? A study using simulated patients. Br J Gen Pract. 1994;44(381):153–6.

131. McLeod PJ. Use of standardized patients to assess between-physician variations in resource utilization. JAMA J Am Med Assoc. 2003;278(14):1164–8.

132. Katz JN, Chang LC, Sangha O, Fossel AH, Bates DW. Can Comorbidity Be Measured by Questionnaire Rather than Medical Record Review? Med Care. 1996;34(1):73–84.

133. Lawthers A, Palmer H, Banks N, Garnick D, Fowles J, Weiner J. Designing and using measures of quality based on physician office records. J Ambul Care Manage. 1995;18(1):56–72.

134. Hayden JA, Tougas ME, Riley R, Iles R, Pincus T. Individual recovery expectations and prognosis of outcomes in non-specific low back pain: Prognostic factor exemplar review. Cochrane Database Syst Rev. 2014;2014(9).

135. McMaster University. Rapid Synthesis, Creating Rapid-learning Health Systems in Canada. 2018.

136. Menear M, Blanchette MA, Demers-Payette O, Roy D. A framework for value-creating learning health systems. Heal Res Policy Syst. 2019;17(1):1–13.

137. McMaster University. Canadian Guideline for Safe and Effective Use of Opioids for Chronic Non-Cancer Pain [Internet]. Available from: http://nationalpaincentre.mcmaster.ca/opioid/cgop_b_app_b08.html

Appendix A: Length of stay definitions used in previous literature

Author (Reference)	Study Title	Extended LOS Definition
Basques (67)	Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis	Continuous
Basquesc (76)	Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion	> 75th percentile
Gruskay (73)	Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis	> 5 days (at least 1 SD > mean)
Siemionow (122)	Predictive factors of hospital stay in patients undergoing minimally invasive transforaminal lumbar interbody fusion and instrumentation	> 24 hours
Zheng (102)	Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation	Continuous
McGirt (95)	Predictors of extended length of stay, discharge to inpatient rehab, and hospital readmission following elective lumbar spine surgery: introduction of the Carolina-Semmes Grading Scale	≥ 7 days

Note. LOS = length of stay, SD = standard deviation, ACS-NSQIP = American College of Surgeons National Surgical Quality Improvement Program. LOS definitions were the same for bivariate and multivariate analyses, with the exception of Basques (67) and Gruskay (73), who considered LOS continuously under multivariable analysis.

Appendix B: Literature review

Author (Reference)	Study Title	Average Age (years)	N	Exposures			Effect Measure and Size	
				Preoperative	Intraoperative	Postoperative	Unstd. B COEFF	Std. B COEFF
Linear regression: LOS considered as continuous								
Basques (67)	Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis	66.4 (11.7)	2358	Age BMI ASA 3-4			0.3	
Basques (76)	Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion	60.6 (13.9)	1861	Age Morbid obesity (BMI ≥ 40) ASA class ≥ 3			0.34 1.42 0.58	0.14 0.11 0.09
					Operative time ≥ 268 mins. Multilevel procedure Transfusion		0.97 0.78 1.76	0.13 0.09 0.22
Gruskay (73)	Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis	60.9 (13.6)	103	Age ASA History of heart disease				0.209 0.334 -0.301
						Discharge to sub-acute /nursing facility		0.376

Note. Statistically significant ($p < 0.005$) characteristics associated with extended LOS following elective lumbar spine surgery found in previous retrospective cohort studies using multivariable regression analyses. Unstd. B COEFF = unstandardized beta coefficient, Std. B COEFF = standardized beta coefficient, BMI = body mass index, ASA = American Society of Anesthesiology, ACS-NSQIP = American College of Surgeons National Surgical Quality Improvement Program.

Author (Reference)	Study Title	Average Age (years)	N	Exposures			Effect Measure and Size	
				Preoperative	Intraoperative	Postoperative	Unstd. B COEFF	Std. B COEFF
Siemionow (122)	Predictive factors of hospital stay in patients undergoing minimally invasive transforaminal lumbar interbody fusion and instrumentation	52 (13)	104	Hemoglobin			-0.25	-0.333
				Oxycodone use			0.041	0.243
					Total fluid input at end of case		0.004	1.911
					Fluid balance		0.003	1.681
					Crystalloid to colloid ratio		4.108	3.021
					Colloids administered		-0.03	-2.196
					Fraction of inspired oxygen		-0.847	-0.222
						Creatinine	3.816	1.579
Zheng (102)	Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation	54	112	Age				0.38
Logistic regression: extended stay considered as ≥ 7 days								
McGirt (95)	Predictors of extended length of stay, discharge to inpatient rehab, and hospital readmission following elective lumbar spine surgery: introduction of the Carolina-Semmes Grading Scale	69.6% < 70, 30.4% ≥ 70	6921	Fusion (no/ yes)				1.2
				ASA class (1-3/4-5)				0.822
				Age (< 70/≥ 70)				0.544
				ODI (< 70/ ≥ 70)				0.52
				Diabetes (no/ yes)				0.379
				Ambulation (independent/ assisted)				0.539

Note. Statistically significant ($p < 0.005$) characteristics associated with extended LOS following elective lumbar spine surgery found in previous retrospective cohort studies using multivariable regression analyses. Unstd. B COEFF = unstandardized beta coefficient, Std. B COEFF = standardized beta coefficient, BMI = body mass index, ASA = American Society of Anesthesiology, ACS-NSQIP = American College of Surgeons National Surgical Quality Improvement Program.

Appendix C: Data dictionary

Variable Name	Variable Description/Question	Data Source	Data Values	Date type
Preoperative				
Sex	Gender of participant	Anesthesia record	1 = male 2 = female	Dichotomous
DOB	Date of birth	Anesthesia record	e.g. yyyy-mm-dd	Date
Surg_date	Date of surgery	Anesthesia record	e.g. yyyy-mm-dd	Date
Admit_date	Date of admission	Anesthesia record	e.g. yyyy-mm-dd	Date
Disch_date	Date of discharge	Anesthesia record	e.g. yyyy-mm-dd	Date
Revision	Revision surgery	Operative Report	0 = no 1 = yes	Categorical
ASA	ASA score	Anesthesia record	e.g. 4	Integer
Comor_CVD	Does the patient have cerebrovascular disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_MI	Has the patient had a myocardial infarction?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_CHF	Does the patient have congestive heart failure?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_PVD	Does the patient have peripheral vascular disease?	Anesthesia record	0 = no 1 = yes	Categorical
Smoking	Smoker within the last year before initial surgery?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_CPD	Does the patient have chronic pulmonary disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_ulcer	Does the patient have ulcer disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_liver_mild	Does the patient have mild liver disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_liver	Does the patient have moderate or severe liver disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_diab_organ	Does the patient have diabetes with end-organ damage?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_diab_wo_organ	Does the patient have diabetes without end organ damage?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_CTD	Does the patient have connective tissue disease?	Anesthesia record	0 = no 1 = yes	Categorical
Comor_hemipl	Does the patient have hemiplegia?	History and physical report	0 = no 1 = yes	Categorical

Variable Name	Variable Description/Question	Data Source	Data Values	Date type
Comor_renal	Does the patient have moderate or severe renal disease?	History and physical report	0 = no 1 = yes	Categorical
Comor_aids	Does the patient have AIDS?	History and physical report	0 = no 1 = yes	Categorical
Comor_met_tumor	Does the patient have a metastatic solid tumour?	History and physical report	0 = no 1 = yes	Categorical
Comor_lymph	Does the patient have a malignant lymphoma?	History and physical report	0 = no 1 = yes	Categorical
Comor_leuk	Does the patient have leukemia?	History and physical report	0 = no 1 = yes	Categorical
Comor_nonmet_tumor	Does the patient have any non-metastatic solid tumor?	History and physical report	0 = no 1 = yes	Categorical
Comor_dementia	Does the patient have dementia?	History and physical report	0 = no 1 = yes	Categorical
Start_HGB	Starting hemoglobin for surgery	Laboratory report	e.g. 12.4	Continuous
BMI	Body mass index at the time of surgery	Operative report: pre-operative	e.g. 25.0	Continuous
Narcotic_use	Narcotic use prior to surgery (hydromorphone/morphine/oxycodone, methadone, fentanyl patch)?	Operative report: pre-operative	0 = no 1 = yes	Categorical
Narcotics_use_drugA	What is your current use of narcotics (drug A) before surgery?	Operative report: pre-operative	0 = none/other 1 = hydromorphone/morphine/oxycodone, as needed 2 = hydromorphone/morphine/oxycodone, daily 3 = methadone 4 = fentanyl patch	Categorical
Nacotics_drugA_amt	What is the dose in milligrams of narcotics (drug A) taken before initial surgery?	Operative report: pre-operative	e.g. 25.0	Continuous
Narcotics_use_drugB	What is your current use of narcotics (drug B, if applicable) before surgery?	Operative report: pre-operative	0 = none/other 1 = hydromorphone/morphine/oxycodone, as needed 2 = hydromorphone/morphine/oxycodone, daily 3 = methadone 4 = fentanyl patch	Categorical

Variable Name	Variable Description/Question	Data Source	Data Values	Date type
Nacotics_drugB_amt	What is the dose in milligrams of narcotics (drug B) taken before initial surgery?	Operative report: pre-operative	e.g. 25.0 mg	Continuous
AD	Anti-depressants prior to surgery?	Operative report: pre-operative	0 = no 1 = yes	Categorical
Neuro	Neuroleptics prior to surgery?	Operative report: pre-operative	0 = no 1 = yes	Categorical
Insur_status	Is there an insurance claim (WSIB or WCB) associated with this case?	Inpatient registration form	0 = no 1 = yes	Categorical
Operative				
Intra_op_analg_1	Intraoperative analgesia medications during surgery	Anesthesia record	0= fentanyl or remifentanil 1= hydromorphone 2= morphine	Categorical
Intra_op_analg_2	Intraoperative analgesia medications during surgery	Anesthesia record	0 = hydromorphone or morphine (long acting) 1 = fentanyl or remifentanil (short acting)	Categorical
Intra_op_analg_dose	What is the dose in milligrams of analgesics taken?	Anesthesia record	e.g. 1.2	Continuous
Trans_during	Was a transfusion required during the surgery?	Anesthesia record	0 = no 1 = yes	Categorical
Blood_loss	The estimated volume of blood lost during initial surgery (in milliliters)	Anesthesia record	e.g. 150 ml	Integer
Surg_start	Start time of surgery	Operative record: intra-operative	e.g. 21:00 (4 digits based on 24hr clock)	Integer
Surg_end	End time of surgery	Operative record: intra-operative	e.g. 21:00 (4 digits based on 24hr clock)	Integer
Operating_surgeon	Who performs the initial surgery?	Operative report	1 = Bill Oxner 2 = Andrew Glennie 3 = Bill Oxner + Andrew Glennie	Categorical

Variable Name	Variable Description/Question	Data Source	Data Values	Date type
Init_Diagnosis	Patients grouped by surgical diagnosis	Operative report	1 = degenerative spondylolisthesis 2 = isthmic spondylolisthesis 3 = disc herniation 4 = spinal stenosis 5 = degenerative scoliosis 6 = idiopathic scoliosis 22 = hardware failure (rod/screw breakage) 23 = hardware failure (fixation in bone) 24 = non-union/malunion 25 = adjacent segment disease 26 = symptomatic screw malposition 27 = persistent dural leak 28 = epidural hematoma	Categorical
Surgery_group	Patients grouped by surgery performed	Operative report	1 = TLIF – 1 level 2 = TLIF – 2 level 4 = discectomy 5 = laminectomy 8 = ALIF	Categorical
Intra_op_comp	Intraoperative complications	Operative report	0 = none 1 = airway/ventilation 2 = allergic reaction 3 = cardiac arrest/failure/arrythmia 4 = cutaneous injury 5 = dural tear 6 = hypotension 7 = implant/instrument related 8 = incorrect operative site 9 = instrumentation/fixation/implant or mispositioning requiring revision 10 = massive blood loss 11 = neural injury spinal cord 12 = neural injury nerve root 13 = vascular injury	Categorical
Surg_comp	Intraoperative complications		0 = none 1 = dural tear 2 = significant complication	

Variable Name	Variable Description/Question	Data Source	Data Values	Date type
Postoperative				
Post_HGB	Hemoglobin following surgery (24 hours)	Laboratory report	e.g. 12.4	Continuous
Trans_after	Was a transfusion required following the surgery?	Laboratory report	0 = no 1 = yes	Categorical
Note. Missing data coded as 99, SCI = spinal cord injury, ACDF = anterior cervical discectomy and fusion, TLIF = transforaminal lumbar interbody fusion, ALIF = anterior lumbar interbody fusion.				

Appendix D: Study populations in previous retrospective cohort studies

Author (Reference)	Study Title	Diagnosis	Surgical Intervention	Mean Age (years)	Mean LOS (days)	N
Basques (67)	Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis	Lumbar spinal stenosis	Elective lumbar laminectomy	66.4 (11.7)	2.1 (2.6)	2358
Basques (76)	Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion	Unspecified	Elective posterior lumbar fusion (minimally invasive and open)	60.6 (13.9)	Normal stay group: 2.9 (1.0) Extended stay group: 7.4 (4.5)	1861
Gruskay (73)	Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis	Unspecified	Elective, open, one- to three-level posterior lumbar instrumented fusion (with or without decompression)	60.9 (13.6)	3.6 (1.8)	103
Siemionow (122)	Predictive factors of hospital stay in patients undergoing minimally invasive transforaminal lumbar interbody fusion and instrumentation	Degenerative conditions	One-level, minimally invasive transforaminal lumbar interbody fusion and instrumentation	52 (13)	2.3 (1.2)	104
Zheng (102)	Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation	Degenerative lumbar spine disorders	Revision posterior lumbar spine decompression, fusion with segmental instrumentation	54	6 (2.4)	112
McGirt (95)	Predictors of extended length of stay, discharge to inpatient rehab, and hospital readmission following elective lumbar spine surgery: introduction of the Carolina-Semmes Grading Scale	Stenosis, spondylolisthesis, symptomatic mechanical disc collapse, revision surgery (including recurrent same-level disc herniation and adjacent segment disease)	First-time elective 1-3 level degenerative lumbar spine surgery	Unspecified (69.6% < 70, 30.4% ≥ 70)	Unspecified (4.2% had extended LOS (≥ 7 days))	6921

Note. LOS = length of stay, ACS-NSQIP = American College of Surgeons National Surgical Quality Improvement Program.

Appendix E: Charlson comorbidity weighted index

Weights	Clinical Condition
1	Myocardial infarction
	Congestive heart failure
	Peripheral vascular disease
	Dementia
	Cerebrovascular disease
	Chronic pulmonary disease
	Connective tissue disease
	Ulcer disease
	Liver disease (mild)
	Diabetes
2	Hemiplegia
	Renal disease (moderate/severe)
	Diabetes with end organ damage
	Non-metastatic solid tumor
	Leukemia
	Malignant lymphoma
3	Liver disease (moderate/severe)
6	Metastatic solid tumor
	Acquired immunodeficiency syndrome (AIDS)

Appendix F: Study characteristics by length of stay outcome

Variables	LOS		
	Median, IQR	Mean (SD)	Range
Preoperative			
Sex			
Male	3 [1-4]	3.22 (3.24)	0-25
Female	3 [1-5]	3.52 (3.17)	0-21
Age (years)			
< 50	0 [0-3]	1.58 (2.13)	0-12
50-59	3 [2-4]	2.89 (2.05)	0-10
60-69	3 [2-5]	3.81 (2.81)	0-17
70-79	4 [3-6]	4.77 (3.86)	0-25
≥ 80	4 [3-7]	5.38 (4.4)	1-21
BMI (kg/m2)			
Normal (18.5-24.9)	3 [0-4]	2.63 (2.38)	0-12
Overweight (25-29.9)	3 [1-5]	3.09 (2.95)	0-21
Obese (≥ 30)	3 [2-5]	3.88 (3.57)	0-25
ASA classification			
1-2	3 [1-4]	2.92 (2.82)	0-21
3-4	4 [3-6]	4.77 (3.84)	0-25
Revision surgery			
Yes	4 [3-6]	4.54 (3.16)	0-17
No	3 [1-4]	3.07 (3.15)	0-25
Smoking status			
Yes	3 [0-4]	2.55 (2.21)	0-8
No	3 [1-5]	3.71 (3.48)	0-25
CCI score			
0-2	3 [1-4]	3.18 (2.88)	0-21
≥ 3	4 [3-6.5]	6.57 (5.63)	1-25
Hemoglobin (g/L)			
< 130	4 [2-6]	4.69 (4.0)	0-25
≥ 130	3 [1-4]	3.07 (2.7)	0-16
Preoperative narcotic use			
Yes	3 [1-5]	3.63 (3.38)	0-17
No	3 [1-4]	3.28 (3.13)	0-25
Preoperative neuroleptic use			
Yes	3 [1-5]	3.49 (3.26)	0-17
No	3 [1-4]	3.32 (3.17)	0-25
Preoperative antidepressant use			
Yes	4 [2-5]	3.86 (3.2)	0-21
No	3 [1-4]	3.11 (3.18)	0-25
WCB insurance status			
WCB claim	2 [0-4]	2.19 (2.08)	0-7
No claim	3 [1-5]	3.46 (3.26)	0-25

Variables	LOS		
	Median, IQR	Mean (SD)	Range
Preoperative			
Initial Diagnosis			
Degenerative spondylolisthesis	4 [3-5]	4.25 (2.61)	0-21
Isthmic spondylolisthesis	3 [2-5]	3.63 (2.37)	0-12
Disc herniation	0 [0-2]	1.14 (2.18)	0-14
Spinal stenosis	3 [2-4]	3.85 (3.6)	0-25
Scoliosis	5 [4-7]	6.2 (3.45)	3-16
Hardware failure fixation in bone	6.5 [3-10]	6.5 (4.95)	3-10
Adjacent segment disease	5 [4-7.5]	5.72 (2.96)	2-16
Non/mal-union	4 [3-6]	5.55 (4.23)	1-17
Operative			
Surgery group			
Laminectomy	2 [1-4]	2.9 (2.95)	0-21
Discectomy	0 [0-1]	0.91 (1.99)	0-12
1-level TLIF	4 [3-6]	4.62 (2.98)	1-25
2-level TLIF	4 [3-6]	5.2 (3.22)	2-16
ALIF	3.5 [2-6]	4.5 (2.86)	2-12
Intraoperative analgesics			
Hydromorphone/morphine (long acting)	3 [1-5]	3.65 (3.4)	0-25
Fentanyl/remifentanil (short acting)	2 [0-4]	2.66 (2.59)	0-12
Operative time (hours)			
< 1	1 [0-2]	1.78 (2.65)	0-14
1-2	2 [0-4]	2.86 (2.89)	0-17
2-3	4 [3-5]	4.42 (2.76)	0-21
> 3	5.5 [3-6]	6.27 (5.16)	2-25
Operating surgeon			
Surgeon 1	2 [0-4]	2.58 (2.89)	0-16
Surgeon 2	4 [2-5]	4.2 (3.34)	0-25
Both	3.5 [1.5-4]	3.42 (2.75)	0-10
Intraoperative complications			
Dural tear (minor)	3 [2-5]	4.32 (4.11)	0-21
Major	4.5 [2-10]	6.0 (5.55)	0-15
None	3 [1-4]	3.29 (3.09)	0-25
Postoperative			
Postoperative blood transfusion			
Yes	8.5 [6-14]	10.75 (6.94)	4-25
No	3 [1-4]	3.29 (2.97)	0-21

Note. LOS = length of stay, BMI = body mass index, ASA = American Society of Anesthesiology, CCI = Charlson comorbidity index, WCB = Workers' Compensation Board, TLIF = transforaminal lumbar interbody fusion, ALIF = anterior lumbar interbody fusion.

Appendix G: Missingness in comorbidity data

Clinical Condition	Missing values N (%)
Myocardial infarction	0
Congestive heart failure	0
Peripheral vascular disease	0
Dementia	29 (6.1)
Cerebrovascular disease	0
Chronic pulmonary disease	0
Connective tissue disease	3 (0.6)
Ulcer disease	0
Liver disease (mild)	0
Diabetes	0
Hemiplegia	28 (5.9)
Renal disease (moderate/severe)	1 (0.2)
Diabetes with end organ damage	0
Non-metastatic solid tumor	30 (6.3)
Leukemia	30 (6.3)
Malignant lymphoma	30 (6.3)
Liver disease (moderate/severe)	0
Metastatic solid tumor	30 (6.3)
Acquired immunodeficiency syndrome (AIDS)	28 (5.9)