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ORIGINAL ARTICLE

'After-hours' non-elective spine surgery is associated with increased perioperative adverse events in a quaternary center

Raphaële Charest-Morin[1] · Alana M. Flexman[2] · Michael Bond[3] · Tamir Ailon[1] · Nicolas Dea[1] · Marcel Dvorak[1] · Brian Kwon[1] · Scott Paquette[1] · Charles G. Fisher[1] · John Street[1]

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Abstract

Purpose 'After-hours' non-elective spinal surgeries are frequently necessary, and often performed under sub-optimal conditions. This study aimed (1) to compare the characteristics of patients undergoing non-elective spine surgery 'After-hours' as compared to 'In-hours'; and (2) to compare the perioperative adverse events (AEs) between those undergoing non-elective spine surgery 'after-hours' as compared to 'in-hours'.

Methods In this retrospective study of a prospective non-elective spine surgery cohort performed in a quaternary spine center, surgery was defined as 'in-hours' if performed between 0700 and 1600 h from Monday to Friday or 'after-hours' if more than 50% of the operative time occurred between 1601 and 0659 h, or if performed over the weekend. The association of 'after-hours' surgery with AEs, surgical duration, intraoperative estimated blood loss (IOBL), length of stay and in-hospital mortality was analyzed using stepwise multivariate logistic regression.

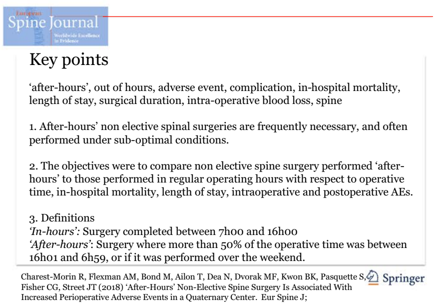
Results A total of 1440 patients who underwent non-elective spinal surgery between 2009 and 2013 were included in this study. A total of 664 (46%) procedures were performed 'after-hours'. Surgical duration and IOBL were similar. About 70% of the patients operated 'after-hours' experienced at least one AE compared to 64% for the 'in-hours' group ($p=0.016$). 'After-hours' surgery remained an independent predictor of AEs on multivariate analysis [adjusted OR 1.30, 95% confidence interval (CI) 1.02–1.66, $p=0.034$]. In-hospital mortality increased twofold in patients operated 'after-hours' (4.4% vs. 2.1%, $p=0.013$). This association lost significance on multivariate analysis (adjusted OR 1.99, 95% CI 0.98–4.06, $p=0.056$).

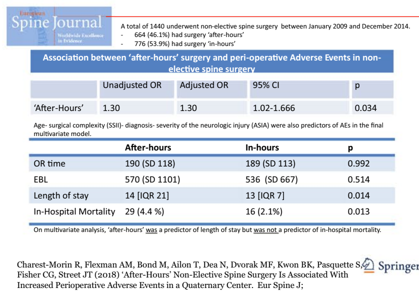
Conclusion Non-elective spine surgery performed 'after-hours' is independently associated with increased risk of perioperative adverse events, length of stay and possibly, mortality. Research is needed to determine the specific factors contributing to poorer outcomes with 'after-hours' surgery and strategies to minimize this risk.

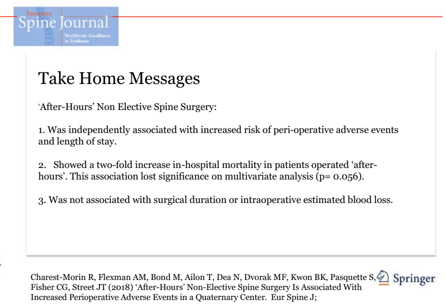
Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-018-5848-x) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.







Keywords 'After-hours' · Out of hours · Adverse event · Complication · In-hospital mortality · Length of stay · Surgical duration · Intraoperative blood loss · Spine

Introduction

According to the Health Care Quality Initiative published by the Institute of Medicine, surgical complications are the second most common cause of preventable mortality and morbidity after medication-related complications [1]. Surgical team fatigue, prolonged working hours and sleep deprivation have been shown to impair surgical performance and increase technical errors in the operating room [2]. In addition, in many centers, 'after-hours' surgery is often performed with a perioperative team less familiar with the specific surgical techniques. Procedures requiring complex spinal instrumentation may be hindered by a lack of specialized biomedical, radiographic and implant personnel during the 'after-hours' period.

The association between adverse events and surgery performed 'after-hours' been reported in anesthesiology and a number of surgical specialties including orthopedic surgery, general surgery, cardiac surgery [3–6]. Dedicated daytime emergency orthopedic trauma rooms implemented to reduce after-hours surgery have improved operating suite flow and decreased complications [7, 8]. However, the relationship between surgical time of day and postoperative outcomes has been variable in different surgical populations, with other studies demonstrating no relationship [4, 9, 10].

At our institution, 'after-hours' surgery is frequently required due to a combination of system and patient factors. When assessed prospectively, spine surgery is associated with a high rate of perioperative adverse events, and we have previously reported an intraoperative and postoperative AE rate for spinal surgery of 10.5 and 73.5%, respectively [11]. However, the relationship between 'after-hours' spine surgery and perioperative AEs has never been studied. Given the vulnerability of the spine population and given the complexity of these interventions from an surgical and anesthetic point of view, the relationship between 'after-hours' surgery and perioperative AEs and mortality is important information. The timing of spine surgery is a potentially modifiable system factor, with the potential to improve patient outcomes. The objectives of this study were to (1) compare the characteristics of patients undergoing non-elective spine surgery 'After-hours' as compared to 'In-hours'; and (2) to compare the perioperative AEs, surgical duration, IOBL, length of stay (LOS) and in-hospital mortality between those undergoing non-elective spine surgery 'after-hours' as compared to 'in-hours'. We hypothesized that 'after-hours' performance of non-elective spine surgery is associated with increased perioperative adverse events, surgical duration, IOBL, LOS and mortality compared to similar cases performed during regular working hours.

Methods

We performed this retrospective study of a prospective cohort with ethics approval from our Institutional Research Ethics Board (H14-03364) with a waiver for informed consent.

Patients and procedures

All consecutive patients who underwent non-elective spine surgery at our institution between January 1st, 2009, to December 31st, 2013, were included in the study. Ours is a Level 1 Trauma Center and quaternary academic teaching center in a major metropolitan center in Canada, with a catchment population of over 4 million people. These patients came from the emergency room or were direct transfer from other peripheral hospitals. Cases were booked by the attending surgeon on a priority basis. At our institution during the period of the study, cases were triaged based on urgency, discussion with the surgeon(s) and time of booking by the in-charge anesthesiologist and nursing team, taking into consideration the urgency of the case as well as operative room access. The date range chosen reflected a period of relatively consistent surgical scheduling practices. Seven fellowship-trained spine surgeons (three neurosurgeons and four orthopedic surgeons), fellows and residents provided surgical care. The attending spine surgeon and anesthesiologist were present at the operation. Between 1600 and 0700 h the nursing, radiology and anesthesiology teams are not specifically subspecialized.

'After-hours' versus 'in-hours' classification

Patients were identified in two groups: the 'in-hours' group defined as surgery occurring between 0700 and 1600 h from Monday to Friday and the 'after-hours' group defined as surgery where greater than 50% of the case was performed between 16h01 and 06h59 from Monday to Friday or when surgery occurred at any time during the weekend (Saturday and Sunday). For example, a surgery starting at 14h00 on a Monday and finishing at 20h00 would be classified in the 'after-hours' group. This left 9 h in the 'in-hours' category and 15 h in the 'after-hours' category. The definition of 'after-hours' is somewhat arbitrary and reflect our institution's practice. At our hospital, from Monday to Friday, 07h00 until 16h00, spine surgery cases are performed with the support of a neuro-anesthesiologist and dedicated nursing and support staff, who are trained in, and experienced in spine surgery. Furthermore, implant/instrument industry representative is usually on site. The percentage of time spent 'after-hour' was calculated by dividing the minutes spent 'after-hours' (between 16h01 and 6h59 from Monday to Friday) by the total surgical duration.

Predictor variables

Based on diagnosis, surgical cases were grouped as follows:

- *Acute trauma* an acute spinal fracture with or without spinal cord injury;
- *Emergent oncology* pathologic fracture, epidural cord compression secondary to a neoplasm or acute neurologic deterioration of an intra-dural tumor;
- *Infection* acute postoperative surgical site infection or primary spondylodiscitis/osteomyelitis/epidural abscess;
- *Degenerative* typically acute disk herniation with nerve root deficit/cauda equina, rapidly progressive cervical myelopathy;
- *Other* e.g., baclofen pump malfunction, postoperative epidural hematoma, active and symptomatic cerebrospinal fluid leak.

Age, gender, American Spinal Injury Association (ASIA) Impairment Scale (AIS) grade, neurologic level and specifics regarding surgery (type of approach, level(s) decompressed, instrumented or fused, type of reconstruction, bone graft utilization, operation date, surgical duration) were collected in a prospective standardized fashion. Comorbidity data were generated retrospectively by review of the Electronic Medical Record. The surgical complexity was calculated using the Spine Surgical Invasiveness Index system (SSII). All data elements for the SSII were prospectively collected in a comprehensive 'operative details' database [12]. The SSII is an instrument that accounts for the number of vertebral levels decompressed, fused and instrumented, as well as the surgical approach. The score ranges from 0 to 48 points, with a higher score indicating greater surgical invasiveness.

Outcome measures

Our primary outcome was any adverse event (AE). All postoperative outcome data were recorded prospectively using the Spine Adverse Event Severity system, version 2 [SAVES V2]. This validated and reliable tool has been used at our institution since 2008 ('Appendix 1' section) [13]. Length of hospital stay, in-hospital mortality, surgery start and end time and estimated blood loss were also collected prospectively.

Statistical analyses

Data were described using mean [standard deviation (SD)], median [interquartile range (IQR)] or percentage, as appropriate. We first compared the characteristics of patients who underwent 'after-hours' surgery with 'in-hours' surgery, using a Chi-squared test, independent *t*-test or analysis of variance as appropriate.

We examined the relationship between 'after-hours' surgery and our primary outcome of any adverse event. To analyze the relationship between 'after-hours' surgery and adverse outcomes, we first compared the patient and procedural characteristics of the populations with and without an adverse event using a Chi-squared test, independent *t*-test or analysis of variance, as appropriate. Unadjusted odds ratios were generated using logistic regression. We used a stepwise multivariate logistic regression model with backward elimination (with a significance level of $p < 0.05$ for inclusion in the model), with the variable 'after-hours' was forced into the model. Model performance was determined using assessments of discrimination (*c*-statistic) and calibration (Hosmer–Lemeshow goodness-of-fit test). When designing this study, it was anticipated that long surgeries (with potentially more AEs) would extend into the ‘after-hours’ period and be included in the ‘after-hours’ group. To further explore and validate the relationship between surgical timing and our primary composite outcomes, we performed a secondary analysis using the ‘percentage of time spent after-hours’, instead of the dichotomous variable ‘after-hours’ using a similar logistic regression model.

Other secondary analyses included examining the relationship between ‘after-hours’ surgery with hospital length of stay, and in-hospital mortality. These relationships were analyzed using Poisson regression, and logistic regression for mortality and length of stay, respectively. Finally, we compared intraoperative blood loss between the ‘in-hours’ and ‘after-hours’ groups using a Wilcoxon sign rank test. All data analysis was performed using SAS Version 9.4 (SAS Institute, Cary, North Carolina) and STATA 12.1 (StataCorp, Texas, USA). All tests were two-tailed and a p value < 0.05 was considered statistically significant.

Although we did not perform a formal sample size calculation, we used a prior study from our institution to estimate that the date range chosen would yield a sufficient sample size of approximately 2000 non-elective spine surgery patients with an 87% rate of adverse event [11].

Results

Study population

A total of 1440 patients underwent non-elective spine surgery and were included in the final analysis. The study population characteristics are summarized in Table 1. A total of 772 (53.8%) procedures were performed during ‘In hours’ and 664 (46.1%) procedures were performed ‘after-hours.’ Of these, 344 (52%), 180 (27%) and 140 (21%) occurred during weekday evenings or nights, weekend days and weekend evenings or nights, respectively. About 48% of the total operative time occurred in the ‘After-hours’ period. Of those grouped as ‘after-hours’, 96% of the operative time occurred in the after-hours periods. Conversely, only 7% of the operative time in the ‘in-hours’ group occurred in the after-hours period.

Comparison between ‘after-hours’ and ‘in-hours’ patient population

The group of patients who underwent ‘after-hours’ surgery was more likely to be younger, smokers, have concurrent polytrauma or malignancy, and have AIS A and B severities of neurologic impairment. SSII, male sex and other comorbidities were similar between the groups. In our multivariate logistic regression below, we controlled for these baseline differences.

Table 1 Study population characteristics, stratified by ‘After-hours’ and ‘In-hours’ surgical timing

	‘After-hours’ group	‘In-hours’ groups	p value
Age (mean SD)	49 (19)	53 (18)	0.0004
Male (%)	443 (67)	487 (63)	0.117
Current smoker (%)	120 (18)	99 (13)	0.004
Comorbidity			
Cardiac	110 (17)	130 (17)	0.355
Pulmonary	65 (10)	75 (10)	0.345
Concurrent polytrauma	130 (20)	92 (12)	< 0.001
Malignancy	79 (12)	119 (15)	0.067
Diabetes	74 (11)	80 (10)	0.353
Hematologic disease	13 (2)	21 (3)	0.103
Immunosuppression	35 (5)	50 (6)	0.287
Neurologic disease	53 (8)	63 (8)	0.268
Polysubstance abuse	18 (3)	18 (2)	0.635
Ankylosing spondylitis	40 (6)	40 (5)	0.304
Previous cord injury	3 (0)	7 (1)	0.305
Diagnosis category			0.0002
Trauma	355 (53)	322 (41)	
Oncology	65 (10)	104 (13)	
Infection	54 (8)	77 (10)	
Degenerative	183 (28)	263 (34)	
Others	7 (1)	10 (1)	
Surgical location			0.1651
Cervical	236 (35)	268 (34)	
Thoracic	231 (35)	294 (38)	
Lumbosacral	184 (28)	189 (24)	
Combined*	13 (2)	25 (3)	
ASIA impairment scale			< 0.001
ASIA A and B (%)	138 (21)	84 (11)	
Unknown (%)	88 (13)	126 (16)	
SSII (mean SD)	8.6 (7)	8.3 (7)	0.4183
Anterior approach to cervical spine (%)	104 (16)	98 (13)	0.098

*Combined refers to the treatment of 2 locations (example: a c5–T1 fusion and a T6–T10 fusion during the same surgical setting)

Primary outcomes: any adverse event

A total of 962 AE occurred (overall AE rate of 67%). Urinary tract infection (25%), pneumonia (20%) and electrolyte imbalance (20%) were the most commons postoperative AEs. About 70% of the patients operated 'after-hours' experienced at least one AE compared to 64% for the 'in-hours' group ($p=0.029$). With the exception of pneumonia, dysphagia and neuropathic postoperative pain (Table 2), the incidence of postoperative adverse events was comparable between the two groups.

One hundred ninety-one intraoperative AEs occurred in 168 patients, giving an overall intraoperative AE rate of 12% (Table 3). The mean number of total AEs per patient was greater in the 'after hours' group compared to the 'in-hours' group [3.0 (SD 5.9) vs. 2.4 (SD 4.4), respectively, $p=0.027$]. There was no difference between the 'after-hours' and 'in-hours' groups with respect to hardware malposition, positioning-related AEs and dural tear.

The unadjusted OR of experiencing any adverse event if surgery occurred 'after-hours' was 1.30 (95% CI 1.04–1.60, $p=0.0196$) ('Appendix 2' section). After stepwise multivariate logistic regression modeling, 'after-hours' status was associated with an adjusted OR 1.30 (95% CI 1.02–1.66, $p=0.034$) of adverse events, with inclusion of age, SSII, diagnosis and ASIA impairment scale as independent predictors of any adverse event (Table 4). Our final model predicted AEs with good discrimination (*c*-statistic 0.77) and acceptable calibration (Hosmer–Lemeshow χ^2 8.09, $p=0.4251$).

Table 2 Frequency of postoperative adverse events

Adverse event	Total population (%)	'After-hours' (%)	'In-hours' (%)	*p* value
Urinary tract infection	365 (25)	177 (27)	188 (24)	0.291
Pneumonia	293 (20)	158 (24)	135 (17)	0.003
Electrolyte imbalance	286 (20)	142 (21)	144 (19)	0.180
Cardiac complication (arrest/failure/arrhythmia/ischemia)	231 (16)	118 (18)	113 (15)	0.103
Delirium	213 (15)	106 (16)	107 (14)	0.246
Neuropathic pain	191 (13)	104 (16)	87 (11)	0.013
Gastro-intestinal complication	112 (8)	58 (9)	54 (7)	0.215
Dysphagia	109 (8)	63 (9)	46 (6)	0.011
Anemia	91 (6)	50 (8)	41 (5)	0.081
Deep wound infection	88 (6)	37 (6)	51 (7)	0.430
Pressure sores	68 (5)	32 (5)	36 (5)	0.872
Systemic infection	65 (5)	29 (4)	36 (5)	0.804
Neurologic deterioration	59 (4)	28 (4)	31 (4)	0.832
Other	54 (4)	30 (5)	24 (3)	0.156
Superficial wound infection	46 (3)	19 (3)	27 (3)	0.506
Deep vein thrombosis or pulmonary embolism	46 (3)	23 (3)	23 (3)	0.597
Hematoma	42 (3)	20 (3)	22 (3)	0.842
Wound dehiscence	36 (2)	17 (3)	19 (2)	0.892
Renal event	26 (2)	12 (2)	14 (2)	0.996
Medication-related issue	23 (2)	13 (2)	10 (1)	0.313
Infection—other site	20 (1)	10 (2)	10 (1)	0.725
Construct failure with loss of correction	17 (1)	7 (1)	10 (1)	0.681
Drain-related issue	15 (1)	9 (1)	6 (1)	0.278
CSF leak/pseudomeningocele	12 (1)	5 (1)	7 (1)	0.756
Hematologic event	12 (1)	7 (1)	5 (1)	0.394
Construct failure without loss of correction	10 (1)	4 (1)	6 (1)	0.697
Dysphonia	8 (1)	4 (1)	4 (1)	0.825
Adrenal insufficiency	4 (0)	1 (0)	3 (0)	0.396
Heterotopic ossification	4 (0)	2 (0)	2 (0)	0.876
Missed fracture	4 (0)	2 (0)	2 (0)	0.876
Cerebro-vascular accident	4 (0)	1 (0)	3 (0)	0.396
Subdural hematoma	3 (0)	3 (0)	0 (0)	0.061
Line-related issue	3 (0)	1 (0)	2 (0)	0.657

Table 3 Frequency of intraoperative adverse events

Intraoperative operative AE	Total population (%)	'After-hours' (%)	'In-hours' (%)	*p* value
Hardware malposition	51 (4)	18 (3)	33 (4)	0.112
Dural tear	50 (3)	28 (4)	22 (3)	0.153
Massive blood loss	35 (2)	18 (3)	17 (2)	0.523
Airway/ventilation	17 (1)	11 (2)	6 (1)	0.122
Anesthesia-related	12 (1)	6 (1)	6 (1)	0.786
Positioning-related	8 (0)	3 (0)	5 (1)	0.624
Nerve root injury	5 (0)	2 (0)	3 (0)	0.784
Cardiac	4 (0)	1 (0)	3 (0)	0.396
Allergic reaction	4 (0)	3 (0)	1 (0)	0.246
Visceral injury	3 (0)	1 (0)	2 (0)	0.657
Hypotension	1 (0)	0 (0)	1 (0)	0.355

Table 4 Predictors of any perioperative adverse events in non-elective spine surgery: multivariate logistic regression model

Variable	Unadjusted OR	Adjusted OR	95% CI	*p* value
'After-hours'*	1.30	1.30	1.02–1.666	0.034
Age	1.03	1.03	1.02–1.04	< 0.001
Diagnosis category				
Degenerative	Ref	Ref		
Infection	2.34	2.52	1.62–3.91	< 0.001
Oncology	4.68	3.23	2.02–5.02	< 0.001
Trauma	2.53	1.96	1.47–2.61	< 0.001
Other	3.15	3.68.33	1.19–11.35	0.023
ASIA				
ASIA A and B	Ref	Ref		
ASIA C, D, E	0.15	0.16	0.10–0.27	< 0.001
ASIA unknown	0.14	0.15	0.06–0.39	< 0.001
SSII***	1.11	1.07	1.05–1.10	< 0.001

*'After-hours' is defined as occurring on the weekend or > 50% after 1600

**Combined refers to the treatment of 2 locations

***Odds ratio for SSI reported per unit increase

When the analysis was repeated using percentage of time spent 'after-hours', the results were similar with an OR of 1.03 per 10% increase in time spent 'After-hours', (95% CI 1.006–1.06, $p = 0.016$), after adjusting for age, diagnosis, ASIA impairment scale and SSII. Weekend or weekday designation was not a predictor of AEs ($p = 0.666$).

Secondary outcomes

Mean length of the surgery was 189 (SD 113) minutes for the 'after-hours' and 190 (SD 118) minutes for the 'in-hours' group ($p = 0.9922$). Estimated blood loss was similar, 534 ml (SD 667) and 571 ml (SD 1101) in the 'after-hours' and 'in-hours' groups, respectively ($p = 0.4087$).

Hospital length of stay was significantly longer in the 'after-hours' group [14 (IQR 7–28) days] compared to the 'in-hours' group [13 (IQR 7–24) days]. The category 'after-hours' was associated with an increased length of stay (unadjusted coefficient 0.16, 95% CI 0.14–0.18, $p < 0.0001$). After adjusting multiple confounders, 'after-hours' remained a significant predictor of LOS (adjusted coefficient 0.04, 95% CI 0.017–0.063, $p = 0.0.001$) the model details are provided in 'Appendix 3' section.

The overall mortality rate in our cohort was 3.1%. Patients who had their surgery performed 'after-hours' were twice as likely to die in hospital as those operated on 'in-hours' with a 4.4% mortality rate versus 2.1% ($p = 0.013$). The unadjusted OR for death was 2.16 (95% CI 1.16–4.02, $p = 0.015$). On multivariate logistic regression analysis, the association between 'after-hours' status and in-hospital mortality was no longer significant (adjusted OR 2.00, 95% CI 0.98–4.05 $p = 0.056$). Age, ASIA impairment scale and a history of active neoplasm were independent predictors of any adverse event (model details are provided in 'Appendix 4' section). Prediction for in-hospital mortality had good discrimination (*c*-statistic 0.89) and acceptable calibration (Hosmer–Lemeshow χ^2 10.39, $p = 0.238$).

Discussion

This is the first study to investigate the impact of performing non-elective spinal surgery cases during the 'out of hours' period on mortality and perioperative complications. Our results demonstrate a significant association between non-elective surgery done 'after-hours' and an increase in perioperative adverse events and hospital length of stay. Our findings were robust to different analyses. Our multivariate analysis demonstrated that 'after-hours', age, ASIA, SSII and the diagnosis category were predictors of AEs. This means even when controlling for 'case surgical complexity, neurologic injury, age and diagnosis, 'after-hours' surgery was associated with more adverse events than the same complexity of surgery done 'in hours'. In-hospital mortality was doubled in cases done 'after-hours', but this association only achieved borderline significance on multivariate regression analysis. These results are sufficiently compelling to warrant further investigation and raise important questions about the potential effects of surgical timing on patient outcomes in patients requiring non-elective spine surgery.

Although our study is novel in identifying this relationship between AE and surgical timing in spine surgery, this issue has been examined in the broader surgical population. Using the National Anesthesia Clinical Outcomes Registry, Whitlock et al. [14] observed that perioperative mortality was associated with a start time after 16h00. Similarly, increased surgical complications have been reported in general surgery, plastic surgery, orthopedic and maxilla-facial surgery when surgery is performed out of regular hours [6, 15–20].

Several factors may explain the relationship between 'after-hours' surgery and poorer patient outcomes. Longer fasting periods and induction of catabolic metabolism have been demonstrated following hip fracture in the elderly where surgical delays beyond 48 h and was associated with increased mortality [21]. Another possible explanation for the higher occurrence rate of AEs may relate to the circadian rhythm. In the cardiac surgery literature, percutaneous coronary intervention performed at night is associated with an increased mortality likely due to biological circadian variation [5]. Provider fatigue may also contribute to poorer perioperative outcomes. Among orthopedic surgeons and residents, O'Brien et al. [22] demonstrated that sleep deprivation altered attention, working memory, and concentration, which can lead to intraoperative adverse events. Lastly, patients operated 'after hours' are more likely to encounter obstacles in their care pathway with delays/errors due to inexperienced/insufficient nursing or medical staff.

Our study results demonstrated that patients operated 'after-hours' were twice as likely to die during their admission compared to patients operated during regular hours. However, this finding did not persist in adjusted analysis. Our results demonstrated that in-hospital mortality was strongly correlated to a history of active malignancy, neurologic injury and age. Interestingly, neither traumatic injury and oncologic indication were predictive of mortality in our population. Our ability to conclusively detect a relationship between 'after-hours' status and postoperative mortality was most likely due to the small number of outcomes in our dataset. Furthermore, the small number of outcomes precludes further subgroup analyses, although there are likely groups in which surgical timing has more importance. In the overall spine population, Street et al. [11] reported a mortality rate of 2.1% but over 90% of the deaths reported occurred in the emergent population, mainly in the traumatic spinal cord injury population. With an in-hospital mortality ranging from 6.5 to 7.5% [23], the impact of AEs on mortality in the traumatic spinal cord injury population should not be overlooked.

Adverse events were reported in 67% of the patients. The vast majority could be overlooked as minor AEs, however, even minor AEs can contribute to patient satisfaction, length of stay and cost. Using the same AE collection system on 1 815 patients who underwent spine surgery, Hellsten et al. [24] reported that AEs accounted for $8.38 million of a single institution's expenses over a 4 years period, with grade 1 and 2 AEs representing 43% of the aggregate cost. Pulmonary complications, our second most frequent AE, have been associated with a major increase in the cost of care by Whitmore et al. [25] ($7233 per complication). Lastly, at our institution, Street et al. [26] demonstrated an increased length of stay associated with decubitus ulcers, delirium, pneumonias and urinary tract infection. These data emphasize the potential significance of even minor AEs.

There are inherent limitations to this study. First, our definition of the 'after-hours' designation is arbitrary, as no clear definition exists although our definition of after-hours was consistent with multiple prior publications [6, 14, 17, 18, 20, 27]. In addition, the characteristics of the two groups were different and, although we adjusted for many confounders in our analysis, residual confounding was possible due to unmeasured confounders. For example, the use of SII to control for surgical complexity may have not completely accounted for all aspects of complexity and led to residual confounding. Furthermore, due to a low incidence and possibly lack of statistical power, we were not able to detect difference between the 'after-hours' and 'in-hours' groups in the occurrence of any specific intraoperative AEs nor are we able to determine the precise reasons for the increase in adverse events after hours. Similarly, our results do not answer the question of whether modifying surgical timing will result in improved outcomes. In addition, due to the retrospective nature of the study, we were unable to report patient-reported outcomes, which would have added to the importance of our findings. Finally, our data represents patterns of practice and a patient population from only a single academic center and may not be reflective of all institutions or practices. We believe the patient population and spectrum of spine pathology served at our institution likely reflects many other tertiary referral hospitals.

'After-hours' surgery is a common practice among spinal surgeons and many reasons dictate surgical timing, such as pathologies with acute neurological deterioration/deficit that require rapid intervention to optimize neurologic recovery.

At our institution, limited access to the operative room is an issue. In this study, 46% of the cases were performed 'after-hours' with half of these done during weeknight/evenings. About 53.89% of the cases performed 'after-hours' were neurologically intact or had a nerve root injury. Therefore, we can assume that a significant percentage of the surgeries that were performed 'after-hours' could have been done in the regular daytime hours and potentially resulted in better patient outcomes. The risk of operating 'after-hours' and the pathologically driven urgency of a case should be weighted when booking a spinal emergency to the operative room. The lack of access to 'In-hours' surgery time, and the associated delays in access, has myriad implications for patient care. Delays can lead to prolonged fasting of patients, omission of normal medications, and often prolonged immobilization in 'spinal precautions', which can result in pulmonary atelectasis among other consequences. The interrelationship between all these factors remains speculative and beyond the scope of this study. However, we believe that our results provide a foundation for further study into this challenging but important subject. Dedicated, daytime operating room time for spine surgery is a potential solution to improve patient outcomes in high volume centers.

Lastly, there are many other intangible aspects of performing 'after-hours' surgery that was not captured in this study. A study published in 2014 demonstrated that there was a significant increase in cost for open tibial fracture operated 'after-hours' [28]. This association has never been studied in spine surgery. 'After-hours' surgery is potentially associated with additional resource consumption, cost and detrimental to health care professionals. At some centers, operative room professionals are a scarce resource and overutilization of these resources 'after-hours' may lead to team fatigue and apathy. Limitation in 'after-hour' surgery in general with increased daytime operating room access could result in wiser spending and better staff morale.

Conclusion

Non-elective spine surgery performed outside the usual daytime operating hours is associated with increased perioperative adverse events and hospital length of stay, even after adjusting for potential confounders. Unadjusted mortality doubles with 'after-hours' surgery although this finding was not robust on adjusted analysis. Our findings raise important questions about the timing of emergency spine surgery in high volume centers.

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Compliance with ethical standards

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Appendix 1

SPINE ADVERSE EVENTS

Intra-Operative Adverse Events
01. Anesthesia Related
02. Cardiac
03. Airway/Ventilation
04. Hypotension (systolic <85mmHg for 15min)
05. Massive Blood Loss (>5L in 24h or >2L in 3h)
06. Cord Injury
07. Nerve Root Injury
08. Dural Tear
09. Vascular Injury
10. Visceral Injury
11. Bone Implant Interface Requiring Revision
12. Hardware Malposition Requiring Revision
13. Hardware Malposition Not Requiring Revision
14. Surgery Cancelled/Delayed
15. Other Intra-Operative Adverse Event

Respiratory
16. Pneumonia
17. Pulmonary Embolus
18. Respiratory/Ventilatory Failure
19. Atelectasis
20. Pleural Effusion
21. Dysphagia
22. Other Respiratory Adverse Event

Cardiac/Hemodynamic
23. Anemia Requiring Transfusion
24. Cardiac Arrhythmia/Myocardial Infarction
25. Deep Vein Thrombosis
26. Other Cardiac/Hemodynamic Adverse Event

Post-Operative Surgical Site
27. Hardware Malposition Requiring Revision
28. Hardware Malposition Not Requiring Revision
29. CSF Leak/Pseudomeningocele
30. Surgical Site Infection
31. Prolonged Incision Drainage/Healing
32. Surgical Site Hematoma
33. Other Surgical Site Adverse Event

Genitourinary
34. Urinary Tract Infection
35. Hematuria/Urethral Trauma (false passages)
36. Urinary Retention
37. Other Genitourinary Adverse Event

Gastrointestinal
38. Ileus/No Bowel Movement for >5d
39. Other Gastro-Intestinal Adverse Event

Neurological
40. Post-Operative Nerve Root Deficit
41. Post-Operative Cord Injury
42. Post Admit/Pre-Op Neuro Deterioration
43. Post-Operative Neurological Deterioration
44. Neuropathic Pain
45. Other Neurological Adverse Event

Consequences Secondary to SCI
46. Autonomic Dysreflexia
47. Heterotopic Ossification
48. Joint Contractures
49. Renal Calculi
50. Shoulder Pain
51. Spasticity
52. Orthostatic Hypotension
53. Other Consequences Secondary to SCI

Other
54. Delirium
55. Pressure Injury/Decubitus Ulcer
56. Psychiatric Disturbance Requiring Treatment
57. Pyrexia of Unknown Origin
58. Escalation of Level of Care
59. Other Not Relevant to Other Body Systems

Appendix 2

See Table 5.

Table 5 Candidate predictors of adverse events

Variable	No AE $N=564$	AE $N=844$	*p* value
Age (mean, SD)	47 (17)	54 (19)	< 0.0001
Male sex (%)	363 (64)	555 (66)	0.590
Diagnosis category			< 0.0001
Degenerative	252 (45)	192 (23)	
Infection	47 (8)	83 (10)	
Oncology	29 (5)	115 (14)	
Trauma	231 (41)	446 (53)	
Others	5 (1)	8 (1)	
Location			< 0.0001
Cervical	163 (29)	336 (40)	
Thoracic	277 (49)	237 (28)	
Lumbosacral	113 (20)	245 (29)	
Combined**	11 (2)	26 (3)	
Anterior approach	83 (15)	119 (14)	0.746
Current smoker	76 (13)	142 (17)	0.089
Cardiac comorbidity	76 (13)	160 (19)	0.007
Pulmonary comorbidity	48 (9)	88 (10)	0.233
Concurrent polytrauma	69 (12)	153 (18)	0.003
Active malignancy	42 (7)	143 (17)	< 0.0001
Diabetes	45 (8)	103 (12)	0.011
Hematologic disease	9 (2)	23 (3)	0.164
Immunosuppression	34 (6)	50 (6)	0.936
Neurological comorbidity	36 (6)	78 (9)	0.054
Ankylosing spondylosis	27 (5)	52 (6)	0.272
Polysubstance abuse	15 (3)	21 (2)	0.842
Previous cord injury	6 (1)	4 (0.5)	0.196
ASIA impairment scale			< 0.0001
Complete (ASIA A and B)	23 (4)	199 (23)	
Partial (ASIA C, D, E, CE, NR, CONUS)	527 (94)	664 (76)	
ASIA unknown	12 (2)	15 (2)	
SSII (mean, SD)***	6.0 (5.4)	10.1 (7.1)	< 0.0001
Percent operative time spent after hours (mean, SD)	45 (47)	51 (46)	0.0006
'After-hours'*	238 (42)	427 (49)	0.02
Weekend	124 (22)	196 (23)	0.666

*'After-hours' is defined as occurring on the weekend or > 50% after 1600

**Combined refers to the treatment of 2 locations

***Odds ratio for SSI reported per unit increase

Appendix 3

See Table 6.

Table 6 Predictors of hospital length of stay

Variable	Adjusted coefficient	95% CI	*p* value
'After-hours'*	0.04	0.017 to 0.063	0.001
Age	0.011	0.010 to 0.012	< 0.001
Male	− 0.004	− 0.029 to 0.021	0.739
Diagnosis category			
Degenerative	Ref		
Infection	0.70	0.65 to 0.74	< 0.001
Oncology	0.47	0.42 to 0.53	< 0.001
Trauma	0.44	0.40 to 0.47	< 0.001
Other	0.28	0.16 to 0.40	< 0.001
Location			
Cervical	Ref		
Thoracic	− 0.39	− 0.42 to − 0.36	< 0.001
Lumbar	− 0.39	− 0.42 to − 0.36	< 0.001
Combined**	0.0012	− 0.061 to 0.059	0.968
ASIA			
ASIA A and B	Ref		
ASIA C, D, E	− 0.78	− 0.81 to − 0.75	< 0.001
ASIA unknown	− 0.53	− 0.62 to − 0.45	< 0.001
SSII***	0.017	0.015 to 0.018	< 0.001
Diabetes	0.24	0.21 to 0.28	< 0.001
Smoker	0.079	0.049 to 0.11	< 0.001
Polysubstance abuse	0.34	0.28 to 0.40	< 0.001
Cardiac disease	0.067	0.036 to 0.096	< 0.001
Pulmonary disease	0.11	0.073 to 0.14	< 0.001
Malignancy	0.13	0.087 to 0.17	< 0.001
Hematologic disease	0.46	0.40 to 0.52	< 0.001
Immunosuppression	0.047	0.00066 to 0.093	0.047
Neurologic comorbidity	0.26	0.23 to 0.30	< 0.001
Previous cord injury	− 0.40	− 0.54 to − 0.24	< 0.001
Ankylosing spondylitis	− 0.23	− 0.27 to − 0.18	< 0.001
Concurrent polytrauma	0.20	0.17 to 0.23	< 0.001
Anterior approach	− 0.16	− 0.19 to − 0.12	< 0.001

*'After-hours' is defined as occurring on the weekend or > 50% after 1600

**Combined refers to the treatment of 2 locations

***Odds ratio for SSI reported per unit increase

Appendix 4

See Table 7.

Table 7 Multivariate analysis: predictors of in-hospital mortality

Variable	Adjusted OR	95% CI	*p* value
'After-hours'*	1.99	0.98–4.06	0.056
Age	1.05	1.02–1.08	< 0.001
Malignancy	9.37	4.32–20.31	< 0.001
Location			
Cervical	Ref		
Thoracic	0.41	0.18–0.92	0.031
Lumbar	0.34	0.11–1.07	0.065
Combined**	2.44	0.60–9.95	0.215
ASIA			
ASIA A and B	Ref		
ASIA C, D, E	0.10	0.04–0.21	< 0.001
ASIA unknown	1.28	0.35–4.73	0.709

*'After-hours' is defined as occurring on the weekend or > 50% after 1600

**Combined refers to the treatment of 2 locations

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Affiliations

Raphaële Charest-Morin[1] · Alana M. Flexman[2] · Michael Bond[3] · Tamir Ailon[1] · Nicolas Dea[1] · Marcel Dvorak[1] · Brian Kwon[1] · Scott Paquette[1] · Charles G. Fisher[1] · John Street[1]

✉ Raphaële Charest-Morin
Raphaele.charestmorin@vch.ca

Alana M. Flexman
alana.flexman@vch.ca

Michael Bond
bondium@gmail.com

Tamir Ailon
Tamir.Ailon@vch.ca

Nicolas Dea
nicolas.deak@vch.ca

Marcel Dvorak
Marcel.dvorak@vch.ca

Brian Kwon
brian.kwon@ubc.ca

Scott Paquette
scott.paquette@vch.ca

Charles G. Fisher
Charles.Fisher@vch.ca

John Street
john.Street@vch.ca

[1] Department of Orthopedic Surgery, Blusson Spinal Cord Centre, University of British Columbia, 6th Floor, 818 West 10th Avenue, Vancouver, BC V5Z 1M9, Canada

[2] Department of Anesthesiology, Pharmacology and Therapeutics, Vancouver General Hospital, University of British Columbia, Room 2449 JPP 899 West 12th Avenue, Vancouver, BC V5Z 1M9, Canada

[3] Department of Orthopaedic Surgery, University of British Columbia, 317-2194 Health Sciences Mall, Vancouver, BC V6T 1Z3, Canada