Research Article

Impact of Surgical Complexity and Instrumentation on Perioperative Outcomes in Cervical Spine Surgery

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Abstract

Open cervical spine surgery is commonly performed for complex spinal conditions requiring instrumentation or multilevel intervention. Although minimally invasive spine surgery (MISS) offers potential benefits in reducing tissue trauma, its applicability in complex cervical procedures is still unclear. This study aimed to evaluate the intraoperative burden and clinical outcomes of open cervical spine surgery in complex cases. This retrospective study evaluated the clinical characteristics and surgical outcomes of patients who underwent cervical spine surgery at Dr. Cipto Mangunkusumo National General Hospital, Jakarta, during the period from August 2021 to August 2023. Data collected included operative time, estimated intraoperative blood loss (EIOBL), postoperative hemoglobin and leukocyte changes, and length of stay (LOS). Patients were stratified by the use of instrumentation and extent of surgery (≥3 versus <3 vertebral levels). The mean operative time was 256 ± 95 minutes, with a mean EIOBL of 252 ± 223 mL. Surgery involving ≥3 vertebral levels was significantly associated with longer operative time (p=0.012), but not with increased EIOBL, laboratory changes, or LOS. Instrumentation, used in 71% of cases, was associated with increased operative time and blood loss, although these differences were not statistically significant. In conclusion, open cervical spine surgery in complex settings increases operative time but does not significantly impact perioperative morbidity. Surgical complexity likely contributes more to intraoperative burden than surgical approach.

Keywords*: cervical spine surgery, minimally invasive spine surgery, open surgery, instrumentation, perioperative outcomes.*

Dampak Kompleksitas Bedah dan Instrumentasi terhadap Luaran Perioperatif pada Operasi Tulang Belakang Servikal

Abstrak

Pembedahan tulang belakang servikal terbuka sering dilakukan untuk menangani kondisi tulang belakang yang kompleks yang memerlukan penggunaan instrumen atau intervensi pada beberapa segmen. Meskipun bedah tulang belakang invasif minimal (MISS) menawarkan potensi manfaat dalam mengurangi trauma jaringan, efektivitasnya pada kasus servikal kompleks masih belum jelas. Penelitian ini bertujuan mengevaluasi beban intraoperatif dan luaran klinis dari pembedahan servikal terbuka pada kasus kompleks. Studi retrospektif ini mengevaluasi karakteristik klinis dan luaran bedah pada pasien yang menjalani operasi tulang belakang servikal di Rumah Sakit Umum Pusat Nasional Dr. Cipto Mangunkusumo, Jakarta, selama periode Agustus 2021 hingga Agustus 2023. Data yang dikumpulkan mencakup durasi operasi, taksiran kehilangan darah intraoperatif (EIOBL), perubahan kadar hemoglobin dan leukosit pascaoperasi, serta lama rawat inap. Pasien dikelompokkan berdasarkan penggunaan instrumen dan luas tindakan (≥3 versus <3 segmen vertebra). Rerata waktu operasi adalah 256 ± 95 menit dengan EIOBL sebesar 252 ± 223 mL. Operasi pada ≥3 segmen vertebra secara signifikan berkaitan dengan waktu operasi yang lebih lama (p=0,012), namun tidak berhubungan dengan peningkatan EIOBL, perubahan laboratorium, atau lama rawat. Penggunaan instrumen pada 71% kasus meningkatkan durasi dan kehilangan darah, meskipun tidak signifikan secara statistik. Kompleksitas tindakan tampaknya lebih berperan dalam beban intraoperatif dibandingkan jenis pendekatannya.

Kata kunci: pembedahan tulang belakang servikal, bedah invasif minimal, pembedahan terbuka, instrumen, luaran perioperatif.

Introduction

In the hands of surgeons proficient in microsurgical techniques, adopting procedures such as hemilaminectomy can enhance surgical precision while minimizing tissue disruption. This approach aligns with the principles of minimally invasive spinal surgery (MISS), which has gained widespread acceptance due to its advantages in reducing surgical trauma, preserving spinal stability, and promoting faster recovery.[1] However, despite these benefits, hemilaminectomy remains underutilized in spinal tumor surgery. Initially introduced over a century ago, it became a recognized approach for spinal tumors more than four decades ago.[2] Concerns over its narrower surgical corridor—believed to increase the risk of spinal cord injury and limit its use to small tumors—have contributed to its limited adoption.

Cervical spine pathology is becoming increasingly prevalent due to an aging global population, further complicating spinal surgery. Cervical spine surgery (CSS) has been shown to improve outcomes in selected patients by reducing morbidity and mortality and alleviating long-term neurological symptoms.[3] While minimally invasive techniques aim to reduce surgical trauma, open surgery continues to play a critical role in managing complex spinal pathologies. In cases requiring extensive decompression, large tumor resections, or multilevel involvement, open laminectomy offers superior exposure, allowing safer tumor removal and more effective spinal reconstruction. The decision between open surgery and MISS is influenced by several factors, including the extent of spinal involvement and the need for instrumentation.[4]

Recent advancements in microsurgical techniques and intraoperative imaging have significantly improved the safety and precision of hemilaminectomy.[5] Studies have demonstrated that it provides sufficient access to intradural spinal tumors while preserving surrounding structures.[6,7] Compared to traditional laminectomy, hemilaminectomy maintains the integrity of posterior spinal elements, potentially reducing postoperative instability and related complications. However, for cases involving large tumor burden, severe spinal cord compression, or major anatomical distortion, open laminectomy remains a dependable option that ensures adequate decompression and surgical access.[2] By integrating both approaches, surgeons can tailor surgical strategies to individual patient needs. This study aims to assess the intraoperative burden and clinical outcomes of open cervical spine surgery in complex cases involving instrumentation and multilevel procedures (three or more levels). Through a cross-sectional analysis of operative time, estimated intraoperative blood loss (EIOBL), and postoperative leukocyte response, the study seeks to determine whether open or minimally invasive approaches offer superior outcomes in challenging surgical scenarios, thereby supporting informed decision-making.

Methods

This retrospective study evaluated the clinical characteristics and surgical outcomes of patients who underwent cervical spine surgery at Dr. Cipto Mangunkusumo National General Hospital, Jakarta, during the period from August 2021 to August 2023. The study included all patients who underwent primary cervical spine procedures for various indications, including degenerative disorders, neoplasms, infections, and traumatic injuries. Patients were eligible if their medical records were complete and included perioperative data such as operative time, estimated intraoperative blood loss (EIOBL), changes in hemoglobin and leukocyte counts, and postoperative clinical outcomes. To ensure data integrity and reduce bias, patients were excluded if their medical records were incomplete, if the surgery did not primarily involve the cervical spine, or if the procedure was a revision surgery. Resurgery cases were analyzed separately and were not included in the main analysis to avoid heterogeneity in surgical burden and recovery profiles. Operative characteristics such as surgical duration and estimated intraoperative blood loss (EIOBL) were also recorded. Laboratory parameters, including changes in hemoglobin (ΔHb) and leukocyte count (ΔWBC), were analyzed alongside the length of hospital stay (LOS). Patients were stratified based on instrumentation use and surgical level involvement (<3 vs. ≥3 vertebrae).

Sample Size Determination

Although the study was retrospective and based on available clinical data, a statistical justification for the sample size was referenced to support the validity of the comparisons made. A priori power analysis based on a two-tailed independent samples t-test, with an expected moderate effect size of 0.6, an alpha level of 0.05, and a power of 80%, suggested a minimum of 44 subjects would be needed to detect statistically meaningful differences between two groups, such as those stratified by instrumentation or surgical level. This calculation aligns with methodological guidance which emphasized the importance of statistical power analysis in ensuring reliability in spine surgery research.[8] Therefore, the inclusion of 48 patients in this study was considered adequate to achieve sufficient power for the planned analyses and subgroup comparisons.

Statistical Analysis

Descriptive statistics were used to summarize baseline characteristics. Categorical variables were reported as frequencies and percentages, while continuous variables were presented as means with standard deviations. The normality of data distribution was assessed using the Shapiro-Wilk test. Comparative analyses were performed using the independent t-test or Mann-Whitney U test for continuous variables, as appropriate. The Spearman's correlation test was applied to evaluate associations between surgical level and EIOBL, ΔHb, ΔWBC, and LOS. A p-value <0.05 was considered statistically significant.

Results

During the study period, a total of 248 spinal surgeries were performed, of which 58 specifically involved the cervical spine. Among these, 48 cases met the inclusion criteria for analysis. Two patients required reoperation, and no postoperative infections were reported in the study cohort.

Demographic and Clinical Characteristics

A total of 48 patients underwent spinal surgery, with a mean age of 48.65 ± 17.01 years. The majority of patients were male (52%), while females accounted for 48%. Regarding the pathological basis, degenerative conditions were the most prevalent (45.9%), followed by tumors (35.4%), infections (10.4%), and trauma (8.3%). The mean operative time was 256 ± 95 minutes, with a mean estimated blood loss of 252 ± 223 mL. Vertebral involvement was observed in <3 levels in 44% of cases, while 56% of patients had surgery involving ≥3 levels, and 10.4% had craniocervical junction (CCJ) involvement. Instrumentation was utilized in 71% of cases, whereas 29% of procedures were performed without implant placement. Laboratory findings demonstrated a mean hemoglobin decrease (ΔHb) of -1.25 ± 3.10 g/dL and a mean change in white blood cell count (ΔWBC) of 5509 ± 9644. The mean LOS was 9.3 ± 9.8 days (Table 1).

Table 1. Demographic and Clinical Characteristics of Patients Undergoing Spinal Surgery

Characteristic	Frequency
Demographics	
Age, mean ± SD, years	48.65 ± 17.01
Sex, n (%)	
Male	25 (52)
Female	23 (48)
Clinical Parameters	
Pathological basis, n (%)	
Degenerative	22 (46)
Tumor	17 (35)
Infection	5 (10)
Trauma	4 (8)
Operative Characteristics	
Operative time, mean ± SD, min	256 ± 95
Estimated blood loss, mean ± SD, mL	252 ± 223
Vertebral levels involved, n (%)	
<3 vertebrae	21 (44)
≥3 vertebrae	27 (56)
Craniocervical Junction	5 (10)
Surgical Intervention	
Instrumentation/Implant, n (%)	
Yes	34 (71)
No	14 (29)
Laboratory Parameters, mean ± SD	
Delta Hb	-1.25 ± 3.10
Delta WBC	5509 ± 9644
Length of Stay (mean ± SD, days)	9.3 ± 9.8

Hb=Haemoglobin; SD=Standard Deviation; WBC=White Blood Cell

Surgical Outcomes

When stratified by instrumentation, operative time was slightly longer in the instrumentation group (265.74 ± 89.89 minutes) compared to the non-instrumentation group (233.57 ± 105.86 minutes), though the difference was not statistically significant (p=0.114). However, patients with ≥3 vertebral levels involved had significantly longer operative durations (285.19 ± 96.18 minutes) than those with <3 levels (219.29 ± 80.86 minutes, p=0.012). Blood loss was similar between groups, with no significant difference between instrumentation (222.94 ± 208.73 mL) and non-instrumentation (322.14 ± 249.96 mL) cases (p=0.170). Similarly, blood loss did not significantly differ between cases involving <3 levels (228.57 ± 213.48 mL) and ≥3 levels (270.00 ± 233.35 mL, p=0.391). Hemoglobin reduction was greater in the instrumentation group (-1.44 ± 3.58 g/dL) compared to non-instrumentation cases (-0.76 ± 1.19), though this difference was not statistically significant (p=0.207). Inflammatory response, as measured by leukocyte count changes, was higher in the instrumentation group (7.00 ± 14.08 ×10³/μL) than in the non-instrumentation group (4.37 ± 3.25 ×10³/μL), though not statistically significant (p=0.650). Length of hospital stay did not significantly differ between groups, with an average of 5.08 ± 4.44 days in the non-instrumentation group and 5.69 ± 11.17 days in the instrumentation group (p = 0.414) (Table 2).

Table 2. Surgical Outcomes Stratified by Instrumentation and Level Involvement

Category and Parameter	Specification	n	Value	p-value
Operative Characteristics				
Duration (min)	No instrumentation	14	233.57 ± 105.86	0.114
	With instrumentation	34	265.74 ± 89.89	
	<3 levels	21	219.29 ± 80.86	0.012*
	≥3 levels	27	285.19 ± 96.18	
Haemorrhagic Parameters				
Blood Loss (mL)	No instrumentation	14	322.14 ± 249.96	0.170
	With instrumentation	34	222.94 ± 208.73	
	<3 levels	21	228.57 ± 213.48	0.391
	≥3 levels	27	270.00 ± 233.35	
Δ Haemoglobin (g/dL)	No instrumentation	14	-0.76 ± 1.19	0.207
	With instrumentation	34	-1.44 ± 3.58	
	<3 levels	21	-0.83 ± 0.97	0.596
	≥3 levels	27	-1.57 ± 4.04	
Inflammatory Response				
Δ Leukocytes (×10³/μL)	No instrumentation	14	4.37 ± 3.25	0.650
	With instrumentation	34	7.00 ± 14.08	
	<3 levels	21	5.31 ± 9.28	0.284
	≥3 levels	27	5.67 ± 10.01	
Clinical Outcome				
Length of Stay (days)	No instrumentation	14	5.69 ± 11.17	0.414
	With instrumentation	34	5.08 ± 4.44	
	<3 levels	21	7.62 ± 6.62	0.248
	≥3 levels	27	10.59 ± 11.61	

*Values expressed as mean ± standard deviation. *Statistical significance at p<0.05*

Correlation Analysis

Spearman's correlation analysis was performed to assess the relationship between surgical level and various clinical parameters. Estimated intraoperative blood loss (EIOBL) demonstrated a weak positive correlation with surgical level (ρ=+0.142, p=0.336), though this was not statistically significant. Changes in leukocyte count (ΔLeukocytes) exhibited a negligible positive correlation (ρ +0.090, p=0.544). Hemoglobin change (ΔHemoglobin) showed a weak negative correlation with surgical level (ρ=-0.055, p=0.712), while length of hospital stay (LOS) had a weak positive correlation (ρ=+0.154, p=0.296). None of the observed correlations reached statistical significance (p>0.05).

Discussion

This study provides comprehensive insights into the intraoperative burdens and outcomes of complex cervical spine surgery in an Asian tertiary referral center. The findings reveal important patterns in surgical management that warrant attention within contemporary neurosurgical practice.

The patient population in this study was predominantly middle-aged, with a higher proportion of males (52%), which aligns with previous studies indicating a greater prevalence of degenerative spinal conditions and spinal tumors among men.[9,10] Degenerative pathologies were the most frequently encountered (45.9%), followed by tumors (35.4%). Trauma and infections were less common, accounting for 10.4% and 8.3% of cases, respectively. This distribution is consistent with earlier reports identifying degenerative and neoplastic etiologies as the primary drivers for spinal surgery.[11,12]

Operative characteristics in this cohort reflected a high level of complexity. The average surgery lasted 256 minutes, and the mean EIOBL was 252 mL. Over half of the procedures involved three or more vertebral levels, and more than 70% required spinal instrumentation. Hemilaminectomy was the predominant surgical approach, necessitating careful bone work and neural decompression. As anticipated, surgeries involving three or more levels were significantly longer than those involving fewer levels, with mean durations of 285.19 ± 96.18 minutes versus 219.29 ± 80.86 minutes, respectively (p=0.012), supporting previous observations that surgical extent is associated with increased technical demands and exposure times.[13,14]

While the use of instrumentation was associated with longer operative time and greater blood loss, these differences were not statistically significant. Nonetheless, the observed trends are in line with prior literature suggesting that instrumentation adds to surgical burden, although its impact can be mitigated by modern electrocautery and hemostatic techniques.[15,16]

An important physiological observation in this study was the association between operative duration and postoperative leukocyte count. This relationship may reflect a systemic inflammatory response to tissue trauma, with longer surgeries correlating with heightened leukocytosis. Although leukocyte count changes did not differ significantly between subgroups, the pattern supports the notion that surgical duration contributes more directly to inflammatory responses than surgical level alone. These findings are comparable to prior studies showing that minimally invasive techniques may reduce systemic inflammation, although their advantage diminishes in more extensive or multilevel cases.[17,18]

Postoperative hemoglobin reductions and EIOBL were generally greater in multilevel or instrumented procedures, but again, these differences were not statistically significant. This suggests that perioperative blood loss may be influenced as much by intraoperative technique and patient physiology as by the extent of the surgery. This aligns with recent findings emphasizing the importance of preoperative anemia correction and fluid optimization over surgical complexity in maintaining postoperative hemoglobin levels.[19,20]

Interestingly, LOS remained consistent across subgroups, indicating that factors such as surgical level or instrumentation did not significantly prolong hospitalization. This may reflect the adoption of enhanced recovery after surgery (ERAS) protocols and individualized perioperative management strategies, which have

shown promise in standardizing recovery trajectories even in high-complexity cases.[21,22]

Correlation analysis further reinforced the idea that surgical level alone does not predict perioperative outcomes. No significant associations were found between the number of vertebral levels involved and parameters such as blood loss, leukocyte count, hemoglobin changes, or LOS. This supports the growing consensus that outcomes are shaped by multiple variables, including patient comorbidities, bone quality, and surgical or anesthetic techniques, rather than solely by procedural extent.[23,24]

Beyond our dataset, several findings in the literature warrant further attention. One key theme is the role of operative duration as a proxy for surgical complexity and risk. Recent study demonstrated that longer surgeries are independently associated with both intraoperative and postoperative complications. Their analysis showed statistically significant correlations between duration and the likelihood of surgical site complications, rebleeding, and neurologic deficits.[25] These findings emphasize that time is not merely a procedural metric but a marker of cumulative surgical trauma and physiologic stress.

In addition to influencing patient outcomes, extended operative time also carries implications for the surgical team. Surgeons are subject to increasing physical and cognitive fatigue over the course of long procedures. Recent study showed a linear relationship between operative duration and muscular fatigue, particularly in stabilizing muscles such as the brachioradialis. The study demonstrated that muscle fatigue increased substantially as surgeries progressed, with potential consequences for surgical precision and safety.[26] These findings underscore the importance of considering surgeon ergonomics and workload distribution, especially in lengthy or complex operations.

Moreover, longer surgeries and higher blood loss have been linked to prolonged hospital stays and higher costs. A study found that estimated intraoperative blood loss and surgical duration were both independently associated with extended LOS and increased 90-day readmission rates. Although their odds ratios (1.003 and 1.002, respectively) may appear modest, these effects can accumulate over time and across patient populations, ultimately impacting healthcare resource utilization.[27]

Postoperative complications themselves represent a significant cost driver, particularly when they lead to revision surgeries or prolonged recovery. A study reported that patients who developed complications had nearly double the median length of hospital stay and were far more likely to require unplanned revision procedures. This has direct implications for bundled payment systems and value-based surgical care, in which complication rates and hospital LOS are closely scrutinized metrics.

Altogether, the relationships among operative time, blood loss, complications, and healthcare costs form a cumulative risk pathway. A longer surgery often leads to more blood loss, which increases the chance of complications, thereby extending LOS and escalating the total cost of care.[25-28]

One of the strengths of this study is its detailed characterization of patient demographics, surgical parameters, and laboratory findings, offering valuable insights into the intraoperative burden of cervical spine surgery. However, the study has limitations, including a relatively small sample size that may limit statistical power, potential confounding factors such as preoperative functional status, comorbidities, and surgical techniques that were not fully accounted for, and the retrospective design, which introduces selection and information bias. Despite these limitations, the findings contribute to the growing body of evidence on cervical spine surgery and underscore the need for larger prospective studies with multivariate analyses to enhance generalizability and control for confounding variables.

Conclusion

This study provides valuable insights into cervical spine surgery, emphasizing key operative characteristics and perioperative changes. While surgical level was expected to influence perioperative burden, its most notable effect was on operative duration—procedures involving three

or more vertebrae took significantly longer. Notably, operative duration showed a significant association with tissue response to surgical trauma, indicated by postoperative leukocyte count as a marker of inflammatory response. In contrast, other perioperative outcomes such as blood loss, hemoglobin levels, and length of stay showed no significant correlations, suggesting multifactorial influences on surgical outcomes. In complex cervical spine cases, open surgery remains essential to ensure adequate visualization and minimize tissue retraction. Importantly, invasive procedures did not lead to poorer outcomes, underscoring the value of individualized perioperative management. Future studies with larger cohorts and thorough risk adjustments are needed to further optimize surgical strategies and patient care.

Conflict of Interest

All of the authors of this manuscript have no funding nor conflicts of interest to disclose.

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