Surgical Critical Care Utilization in Adult Patients Undergoing Major Non-Cardiac Surgery in Ontario: A Population Based Study

By

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ABSTRACT

Objective: Assess the inter-hospital variation and factors associated with intensive care unit (ICU) admission for adult elective non-cardiac surgical patients in Ontario.

Methodology: Population databases identified 13 surgical groups between January 2006-December 2014. Primary outcome assessed early ICU utilization within 24 hours post-surgery. I described the inter-hospital variation in proportion of patients admitted to ICU, patient and hospital-level factors associated with ICU admission using multilevel logistic regression for each group. Intra-class correlation coefficient (ICC) and median odds ratio (MOR) assessed the association of individual hospitals with ICU admission.

Results: 541,524 patients across 93 hospitals were studied. Early ICU admission varied between 0.9% (hysterectomy) and 90.8% (open abdominal aortic aneurysm repair). ICC ranged between 18% for hysterectomy (MOR 2.3) to 75.9% for endovascular aortic aneurysm repair (MOR 21.5).

Conclusion: Ontario hospitals showed wide inter-hospital variation in early ICU admission with a large proportion of this variation attributable to the admitting hospital.

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1. INTRODUCTION

Over 300 million non-cardiac and cardiac surgical procedures are performed worldwide each year.[1] Demand for these surgical services is expected to rise as the population ages and comorbidity burden increases, particularly among high income countries.[2] Intensive care units (ICUs) have become established in hospital settings in providing advanced, resource-intensive and tailored care for complex and acutely ill patients. While surgical patients form nearly 50% of all critical care admissions, the epidemiology of ICU use for the postoperative management of non-cardiac surgical patients is poorly understood.[3] Optimal care pathways and guidelines regarding the appropriate use of postoperative ICU care have not been established for this patient group, and opportunities exist for further work in this area.

1.1 Thesis Synopsis

This thesis aims to assess early postoperative ICU utilization within 24 hours after surgery in adult patients undergoing major non-cardiac surgery in Ontario. The background section outlines concerns regarding poor outcomes in high-risk patients who undergo complex non-cardiac surgical procedures, the role for delivering postoperative care in ICUs, and what is currently known about ICU utilization and outcomes for surgical patients. Using population-based administrative healthcare datasets, this thesis describes the epidemiology of postoperative ICU utilization among patients undergoing 13 specific non-cardiac surgical procedures, both with respect to rates and predictive factors. The results will promote debate within individual surgical services, hospitals and policy decision makers' circles regarding the current practice of ICU bed utilization. This thesis is the first Canadian study to review surgical utilization of ICUs, and forms the basis for further work to evaluate outcomes related to postoperative ICU use.

2. BACKGROUND

2.1 Patient outcomes for non-cardiac surgery are an important healthcare quality and safety concern.

Over 300 million non-cardiac and cardiac surgical procedures are performed worldwide each year.[1] Although the average in-hospital and 30-day postoperative mortality rate typically ranges from 1% to 3%, there is evidence that most postoperative deaths occur in a small subset of high risk patients.[4-6] A large retrospective cohort study of a wide range of non-cardiac surgical patients in the United Kingdom (UK) ranked a variety of elective and emergency surgical procedures by their in-hospital mortality rate, and found that 12.5% of surgical patients accounted for over 80% of postoperative deaths.[7] This high risk group is older in age with multiple comorbidities and undergoing long and complex intermediate and high risk surgeries such as abdominal aortic aneurysm repair, hip fractures, bowel, pancreatic and lung resection.[7,8] When patients undergoing elective intermediate or high risk non-cardiac surgical procedures in Ontario were ranked based on predicted risk using an externally validated predictive index, McIsaac et al. found that the 5.3% of patients with the highest predicted risk also accounted for over 50% of all postoperative 30-day deaths.[9] High mortality rates are also seen among emergency surgical patients. In a UK study of 20,183 emergency laparotomies across 192 National Health Service hospitals, 30-day mortality risk averaged 11% across these hospital (ranged between 3% for patients < 40 years of age to 24% in patients > 89 years of age).[10]

2.2 Postoperative complications are strong determinants of patient survival.

Postoperative complications are common, and affect 16-44% patients undergoing major non-cardiac surgery.[11-13] Complications typically affect older patients with a greater burden of chronic illness undergoing complex surgery, who have limited physiological reserve to manage the perioperative inflammatory response and hemodynamic stress.[14-16] In a United States (US) retrospective cohort study of 105,951 adult patients undergoing various types of major non-cardiac surgery, the development of a post-surgical complication within 30 days after surgery was identified as an important determinant of postoperative survival.[17] This study assessed 22 complications captured by the National Surgical Quality Improvement Program (NSQIP) including sepsis, pneumonia, myocardial infarction, surgical site infection, stroke, renal dysfunction and pulmonary embolism. Postoperative complications were associated with a significantly increased 30-day mortality risk (13.3% in patients with complications vs. 0.8% without complications) and 69% reduction in long-term survival (follow up averaged 8 years). Another retrospective cohort study conducted in the UK demonstrated that postoperative morbidity (identified using the postoperative morbidity survey), was associated with an increased risk of death for up to 3 years after surgery (relative hazard 2.0, 95% CI 1.32-3.04) in 1362 elective non-cardiac surgical patients.[18,19] Other studies have shown that post-surgical complications prolong length of hospital stay by 114% (95% confidence interval (CI) 100-130%) and increase healthcare costs by 78% (95% CI 68-90%).[17,20] A landmark study by Ghaferi et al. examined mortality following a postoperative complication (commonly termed ‘failure to rescue’) in 84,730 general and vascular patients across 192 US hospitals.[12] This study revealed that the incidence of post-surgical complications were similar across hospitals (16-18%), but death secondary to these complications varied significantly from 12.5% to 21.4% across US institutions. These findings suggest that post-surgical complications are not always preventable, but improving patient care in those who incur complications may improve patient outcomes. This variation in 'failure to rescue' seen by Ghaferi et al. may be attributable to inadequacies in hospital care processes that cause a delay in timely recognition and treatment of complications. Important care processes in this pathway include quality of post-surgical care, availability of medical staff, number and training of nursing staff, nurse-to-patient ratios, access to interventional cardiology services and ICU services.

2.3 What is known about critical care utilization for non-cardiac surgical patients?

Current evidence shows that there is wide inter-hospital variation and generally low utilization of postoperative ICU in studies from Europe and the UK. In 2006, Pearse et al. showed that, while a high-risk patient subgroup accounted for over 80% of postoperative deaths in the UK, less than 15% of them were admitted to an ICU.[7] This was confirmed by the multicentre European Surgical Outcomes Study (EUSOS) of 46,529 patients undergoing several different types of elective and emergency non-cardiac surgical procedures across 28 European countries.[21] The EUSOS study demonstrated that planned ICU admission rates were low (5-8%) with wide variation in ICU use (1.2-16.1%). Furthermore, 73% of patients who died postoperatively were never admitted to an ICU.

Variation in ICU utilization among select elective surgical procedures has been investigated in a study from the US using Medicare data.[22] Wunsch et al. revealed wide inter-hospital variation among 129,227 patients undergoing open and endovascular abdominal aortic aneurysm repair, cystectomy, pancreaticoduodenectomy and esophagectomy procedures. The median (range) hospital-specific ICU admission rate varied from 50% (3.9-100%) for cystectomy to 92% (0-100%) for open abdominal aortic aneurysm.

Aside from varying across surgical procedures, ICU utilization also likely varies across countries. Several key systemic differences are likely to influence international differences in ICU utilization, which include the organization of healthcare systems, physician reimbursement, the amount of government healthcare investment, access and ICU bed capacity. In comparison to the UK, the US has much higher ICU admission rates (1999 vs. 216 per 100, 000), ICU capacity (22 vs. 3.5 ICU beds per 100,000 population) and spends a greater proportion of their gross domestic product on healthcare (15% vs. 7-8%) (Figure 1).[23] Canada is situated between the UK and US, having 12.9 ICU beds and 389 ICU admissions per 100,000 population and spends 11% of its gross domestic product on healthcare.[3,23,24] The variation in number of ICU beds across Canadian provinces is wide and ranges from 9.8 ICU beds per 100,000 population in Alberta to 21.8 ICU beds per 100,000 population in Newfoundland and Labrador.[3] Ontario is situated in the middle at 14.2 ICU beds per 100,000 population. Overall, differences in healthcare systems, reimbursement, and ICU bed numbers are likely to influence access to critical care beds, ICU triage decision making on which patients are admitted to ICUs, and possibly patient outcomes.[7,25] Evidence to support this comes from an international comparison study assessing adult medical ICU admissions in the US versus the UK.[25] This retrospective study showed that patients in the UK had longer hospital stays prior to ICU admission, were more frequently intubated and had a higher severity of illness on admission to the ICU. These findings were attributed to systematic differences between the two countries and the lower number of available ICU beds in the UK, which may influence ICU admission policies. Although Ontario has more ICU beds than the UK, our capacity remains far behind the US. This may lead to differences in how ICU beds are utilized in our province.

2.4 Does postoperative critical care make a difference in the outcomes for non-cardiac surgical patients?

Surgical ICUs specialize in caring for acutely ill patients and have specific organizational and treatment differences compared to standard ward care. ICUs can provide continuous close patient observation, advanced end-organ life support therapies (e.g., mechanical ventilation, vasoactive drug support, extracorporeal membrane oxygenation, renal replacement therapy, invasive monitoring) with higher nurse-to-patient ratios. In addition, ICUs have access to senior medical staff that are trained in the management of acute problems and can respond early while surgical teams are often busy in the operating room. ICU teams use a multisystem approach to patient care and are comfortable managing important postoperative issues such as pain, hypothermia, nutrition, goal directed fluid titration and early patient mobilization.[26] With higher nurse-to-patient ratios, patients will also receive more individualized attention than a general ward. Patients admitted to ICU are managed in either a Level 2 (step down) unit that can provide non-invasive ventilation and limited organ support, or Level 3 units that can provide invasive mechanical ventilation and other organ support therapies.

Despite these theoretical benefits of postoperative ICUs, their actual clinical impact remains controversial with current evidence demonstrating mixed findings. Several studies have evaluated interventions that entail access to ICU settings, such as advanced monitoring techniques and organ support treatments, and shown an improvement in patient outcomes. Studies assessing invasive monitoring techniques (esophageal Doppler, pulmonary artery catheters) have shown a reduction in postoperative mortality (OR 0.48, 95% CI 0.33-0.78) and complications.[27] A recent multicentre randomized controlled trial compared non-invasive ventilation (NIV) to standard oxygen therapy in adult patients who had undergone abdominal surgery and were at high risk of respiratory failure.[28] This trial showed that NIV significantly reduced re-intubation rates (45.5% standard therapy group vs. 33.1% NIV group, absolute difference -12.4%, 95% CI -23.5% to -1.3%, p=0.03), increased ventilation-free days, and reduced pneumonia and other nosocomial infections (31.4% vs. 49.2%, absolute difference -17.8%, 95% CI -30.2% to -55.4%, p=0.003). Of note, benefits associated with these interventions could plausibly be achieved outside of an ICU setting if hospitals have non-ICU settings with staff that can manage the requisite equipment and closely monitor patients' response to treatment.

Postoperative ICU care has also been associated with a reduction in failure-to-rescue rates. This was demonstrated in a multicentre Dutch study of 25,591 colorectal surgical patients managed postoperatively in a ward (Level 1), Level 2 ICU or Level 3 ICU setting. The unadjusted failure to rescue rates were 19% and 16% in a ward or Level

2/3 ICU respectively. In a multivariable analysis, Level 2/3 ICUs were associated with a reduced risk in failure-to-rescue in comparison to ward level care (OR 0.72, 95% CI 0.65-0.88).[29] Beyond the close monitoring and additional treatments offered in ICUs, several organizational factors intrinsic to critical care environments are likely to play a role in lowering failure-to-rescue rates. These include higher nurse-to-patient ratios (adjusted OR 0.91, 95% CI 0.84-0.99), more registered nurses (adjusted OR 0.84, 95% CI 0.77-0.91) and intensivist-led care (adjusted OR 0.88, 95% CI 0.81-0.96).[29-32]

Despite these promising theoretical benefits from postoperative ICU care, several recent studies challenge this assumption. In an American retrospective cohort study conducted by Wunsch et al.,[22] assessment of patient outcomes and costs in 5 elective major non-cardiac surgical procedures revealed no reduction in patient mortality among hospitals with greater use of ICU. Conversely, higher hospital-specific postoperative ICU use was associated with higher hospital lengths of stay and costs in select procedures. Another prospective cohort study assessed the impact of ICU admission post-surgery on in-hospital mortality in 44,814 adult patients undergoing a wide range of elective cardiac and non-cardiac surgical procedures across 27 countries (19 high income, 7 middle income, and 1 low income). This study also failed to identify any evidence of improved patient survival from immediate postoperative admission to ICU.[33]

2.5 What can we learn from the perioperative care pathways for cardiac surgical patients?

Perioperative care pathways of complex non-cardiac surgical patients show wide variation with no guidelines outlining the types of patients and/or surgical procedures that would benefit from routine post-surgical ICU care.[34] This practice contrasts with the heavily protocolized care received by cardiac surgical patients, which is likely to contribute to the significantly lower overall mortality of this patient group (2-3%) in comparison to major non-cardiac surgical patients.[35] This lower risk of mortality observed with cardiac surgery is especially noteworthy since these procedures are long and complex, and are commonly performed on elderly patients with high levels of comorbidity. Management of cardiac surgical patients has several distinct differences, which could form a useful guide for non-cardiac surgical services. Specifically, cardiac surgical patients undergo extensive preoperative evaluation, routine advanced monitoring, and postoperative admission to specialized cardiac ICUs led by specialized teams.

3. RATIONALE: Why is this study important?

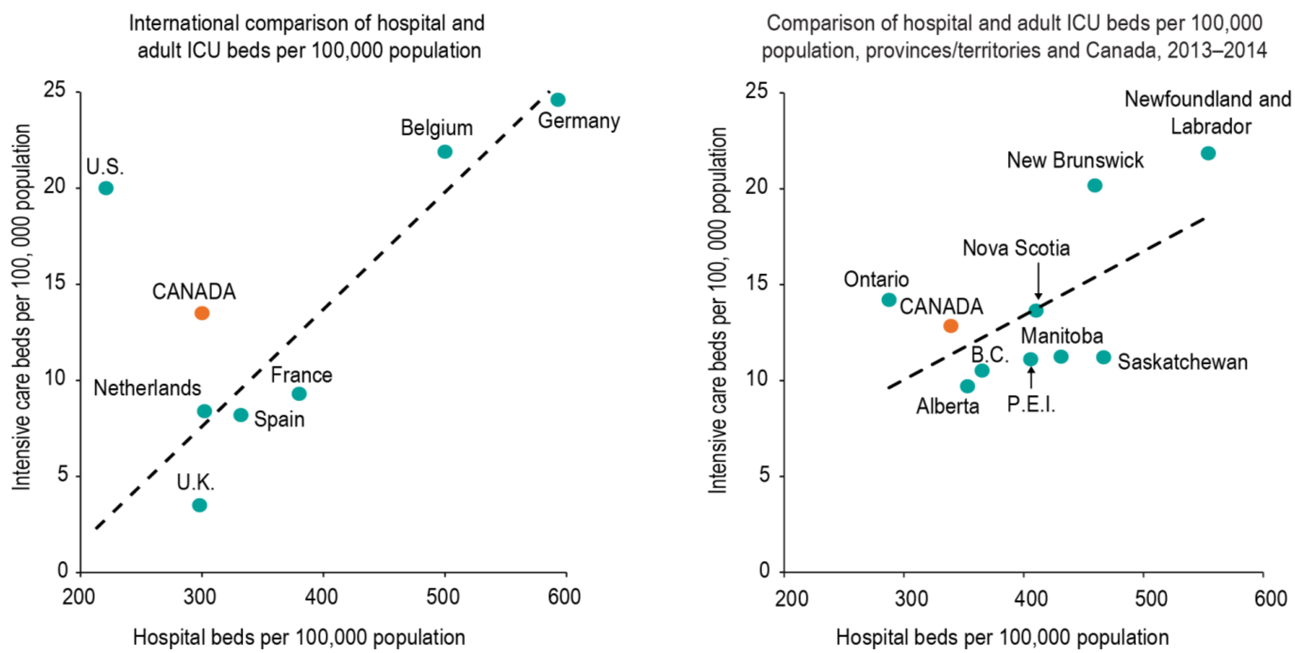
Intensive care units provide specialized care to the most acutely ill patients in hospital environments. However, there is a limited supply of ICU beds and the cost of delivering critical care is high. Canada has a mid-range ICU capacity in comparison to other economically advanced nations, which places it ahead of the UK but markedly behind the US, Germany and Belgium (Figure 1).[3 23] Canada has an ageing population with rising burden of chronic illness.[36,37] This will promote a rise in the demand for surgical services and place a strain on postoperative critical care services.

Ontario is the largest Canadian province with over 13.5 million residents and performs large volumes of complex non-cardiac surgeries. Ontario has 126 hospitals with slightly higher number of ICU beds than the national average.[3,38,39] In 2013/14, there were about 230,800 adult ICU admissions in Canada (excluding Quebec). A substantial portion of these admissions (46%) were elective and urgent surgical patients.[3] At present, no study has specifically assessed post-surgical ICU utilization and factors driving ICU admission in Canada. This thesis will address this issue for adult non-cardiac surgical patients in Ontario and provide new information for healthcare users, providers and health system managers on:

1. The magnitude of inter-hospital variation among surgical services in postoperative ICU care
2. Which factors are associated with ICU admission

Understanding the current patterns of postoperative ICU utilization will promote discussion among healthcare jurisdictions regarding appropriate bed allocation, guide research evaluating outcomes related to postoperative ICU care, and help future planning of ICU resources.

Figure 1: International and Canadian provincial comparisons of critical care and hospital beds.[3,23]



International comparisons (left figure) originally developed and adapted from Wunsch et al. 2008.[23] *National comparisons (right figure) adapted from Canadian Institute for Health Information (CIHI): Care in Canadian ICUs 2016*

4. STUDY HYPOTHESIS AND OBJECTIVES

4.1 HYPOTHESIS

It was hypothesized that large variations exist in rates of early ICU admission for various types of major non-cardiac surgical procedures across Ontario hospitals.

4.2 STUDY OBJECTIVES

There were 2 main study objectives:

1. To evaluate the presence and magnitude of inter-hospital variation in early ICU admission (defined as within 24 hours post-surgery) among different major non-cardiac surgical procedures performed in Ontario.
2. Identify patient-, surgery- and hospital-level characteristics associated with early ICU admission after non-cardiac surgery.

5. METHODOLOGY

5.1 Study design

This thesis was a retrospective cohort study using linked population-based administrative healthcare databases and received ethics board approval from Sunnybrook Health Sciences Centre and University of Toronto (protocol ID number 32639).

5.2 Participants and setting

Eligible patients underwent select major high and intermediate risk surgical procedures between 2006-2014 at Ontario hospitals with Level 2 (non-invasive ventilation and/or limited end organ support) and Level 3 (mechanical ventilation and full hemodynamic support) ICU facilities. For patients who had more than one surgical procedure during their hospitalization or within the study time frame, only the first procedure was included in this study.

5.3 Eligibility criteria

Inclusion Criteria

1. Age ≥40 years of age on the date of the index surgery
2. Major non-cardiac surgery procedures: thoracic (pneumonectomy, lobectomy), vascular (open and endovascular abdominal aortic aneurysm repair, lower limb amputation, lower limb revascularization), intra-abdominal (colorectal, partial liver resection, pancreatic resection, gastrectomy, esophagectomy), orthopedic (spinal surgery, femur surgery, hip surgery, total hip joint replacement, total knee

joint replacement), neurosurgery (craniotomy, posterior fossa surgery) and uro-gynecological (nephrectomy, hysterectomy)

Exclusion Criteria

1. Invalid unique patient key identifier (IKN)
2. Death in the operating room
3. Inter-hospital transfer prior to surgery
4. Preoperative ICU admission

5.4 Administrative data sources

Data were retrieved from linked population-based administrative healthcare databases housed at the Institute of Clinical Evaluative Science (ICES), which is a provincial research institute providing access to Ontario health related data. These databases are regularly updated and linked using unique anonymized patient identifier numbers (IKN).

Patient demographics, socioeconomic status, rurality and mortality were extracted from Vital Statistics, Registered Persons Database (RPDB), PSTLYEAR files and Ontario CENSUS data. The Canadian Institute of Health Information Discharge Abstract Database (CIHI-DAD) provides national information (excluding Quebec) on inpatient hospital stays, discharges and in-hospital deaths. This database was used to identify surgical interventions, admissions associated with trauma, elective or emergency admission status, as well as dates of surgical and ICU admission. The CIHI-DAD and specialized databases (Ontario Diabetes Database, Ontario Health Insurance Plan, Asthma, Congestive Heart Failure, Chronic Obstructive Pulmonary Disease, Ontario Hypertension Database) were used to identify comorbidities using ICD-10 (International

Classification of Diseases) codes and ICD-9 codes for the Ontario Health Insurance Plan (OHIP).[40-44] Use of intraoperative thoracic epidurals, arterial lines, or central venous lines were drawn from the OHIP database. The OHIP administrative database is a repository of physician service claim data. Hospital level variables such as bed numbers, teaching status was obtained from the Information about Ontario health care institutions database. The specific codes used to extract this information are summarized in Tables B1 and B2 (Appendix B).

5.5 Outcome

The primary outcome was early postoperative ICU admission, which was defined as admission on the same day as the index surgery, or within 24 hours after the after the end of surgery. Patients who did not meet this outcome definition were those who were initially admitted to a general ward after surgery. A small proportion of ward patients eventually needed ICU admission more than 24 hours post-surgery; these were defined as 'late ICU admissions'. This definition of early ICU admission was chosen because it captured patients whose post-surgical admissions were planned, as well as any patients unexpectedly requiring ongoing advanced monitoring or treatment that was commenced in the operating room. Thus, this definition captured all patients who had early access to ICU, irrespective of how ICU admission was organized.

5.6 Covariates

Several patient-, surgery- and hospital-level characteristics were extracted from the data sources to help adjust for confounding. Confounding is an important issue given that patients admitted to ICUs are often more complex with higher levels of comorbidities than patients admitted to a ward. In addition, decisions to admit patients to ICUs are likely influence by hospital ICU capacity and individual surgical volumes. Higher volume hospitals will have greater experience, knowledge and resources in the perioperative care of these patients – which in turn may influence patient care and outcomes regardless of whether they are admitted to an ICU bed.

The patient characteristics included demographics (i.e., age, sex), socioeconomic status (expressed as quintile of the median household income from the postcode), rurality, Charlson Comorbidity Index score, and individual comorbidities (including those included in the Charlson score). These comorbidities were prior myocardial infarction, coronary artery disease, heart failure, hypertension, atrial fibrillation, diabetes, peripheral arterial disease, stroke, hemi- or paraplegia, chronic renal insufficiency, dialysis, asthma, chronic obstructive pulmonary disease, dementia, malignancy, liver disease, and rheumatologic diseases.[45,46] This information was extracted based on ICD-10 diagnostic codes from prior hospital admissions within the 3 years prior to date of surgery. Hospital characteristics included teaching status and hospital bed numbers (ICU, surgical and total bed numbers). The volume of 13 individual surgical procedures (as described below) was calculated for each hospital for the duration of the study period.

Surgical information extracted included the type and duration of the surgical procedure, elective or emergency surgery (based on the hospital admission urgency status indicated in the CIHI database) and whether admission was associated with trauma. Surgeries were categorized into clinically similar groups based on their procedural complexity, patient case mix and postoperative course. The 13 categories were open abdominal aortic aneurysm (AAA), endovascular aortic aneurysm repair (EVAR), peripheral arterial disease procedures (above/below knee amputation, lower limb revascularization), open pneumonectomy or lobectomy, video assisted thoracoscopic (VATS) lobectomy, upper gastrointestinal (partial liver resection, biliary bypass, pancreaticoduodenectomy, gastrectomy, esophagectomy), lower gastrointestinal (colorectal resection), major urology (nephrectomy), major gynecology (hysterectomy), neurosurgery, femur, spine, and joint (total hip and knee replacement) surgery.

This approach differs from the previous EUSOS and ISOS studies, which assessed ICU utilization by placing all surgery types together in a single group.[21,33] The approach of simply grouping all surgeries together is limited by the fact that all surgical procedures vary in complexity and patient-case mix. This heterogeneity will inherently influence the need for postoperative ICU among various surgical procedures. The methodology adopted by the EUSOS and ISOS studies results in a very heterogeneous cohort containing a wide variety of surgical procedures and patient case mix – which in turn vary considerably in their need for ICU monitoring and treatment postoperatively. This heterogeneity leads to difficulties in drawing any firm conclusions regarding factors associated with ICU utilization after any surgical procedure. Given these issues, a previous US study conducted by Wunsch et al. studied ICU admission and outcomes for individual surgical procedures.[22]

5.7 Validity of data sources

Several re-abstraction studies assessing the accuracy of the DAD have been performed by CIHI and independently by Juurlink et al.[42,47] The DAD shows high agreement with extracted sex, birthdate, admission date, discharge date, and total length of stay showing an exact match in 98.9-100% records. Documentation of surgical procedures in the DAD shows good accuracy with sensitivity 0.95, positive predictive value (PPV) 0.91 and good agreement (kappa 0.92).[47] Coding accuracy of pre- and post-admission comorbidities are more variable in the DAD, with the accuracy differing between myocardial infarction (sensitivity 0.78, PPV 0.76, kappa 0.76), secondary malignancies (sensitivity 78-82%, PPV 42-51%, kappa 54-61%), and chronic renal failure (sensitivity 0.74, PPV 0.29, kappa 0.40). Specialized and well validated ICES databases were used to ascertain comorbidities such as chronic obstructive pulmonary disease (COPD), diabetes and hypertension. [40,41,48,49] The Ontario COPD dataset contains all prevalent cases since 1991 and uses COPD codes from OHIP, CIHI DAD and Same Day Surgery (SDS) database. The Ontario COPD dataset accurately identifies patients with COPD with a sensitivity of 85%, specificity 78.4% and PPV 57.5%.[43] Similarly, the Ontario Hypertension Database identifies hypertension using OHIP and CIHI DAD and SDS databases. A validation study assessing this dataset has shown high accuracy at identifying adult hypertensive patients with sensitivity of 73%, specificity of 95%, PPV of 87% and negative predictive value of 87%.[44] Validation studies of the Ontario Diabetes Database has shown high accuracy at identifying diabetic patients (sensitivity 86%, specificity 97%, PPV 80%).[40]

ICU admission was identified using the ‘Special Care Unit’ (SCU) code in CIHI-DAD. Recording the SCU code is mandatory for data abstractors in Ontario. This code has date and time (recorded as hour:minute) indicators to indicate the timing of ICU admission and discharge. This code was used to identify early (≤24 hours after surgery) ICU admission, late (>24 hours after surgery) ICU admission and length of ICU stay.

Two validation studies assessing the accuracy of the CIHI-SCU code have been performed in Ontario and Winnipeg, Manitoba.[50,51] These studies compared the SCU code to the Winnipeg ICU database (WICUDB) and Ontario Critical Care Research Network (CCR) patient registry. The WICUDB and CCR databases collect extensive information on admitted ICU patients including admission date and time. The SCU code showed good accuracy at identifying ICU care with sensitivity values ranging from 92% to 97.2%, specificity values exceeding 99%, positive predictive values ranging from 84% to 98.7% and negative predictive values exceeding 99%.

5.8 Study timeline

The dates of the index surgeries occured between 1st January 2006 and 31st December 2014 (Figure 2). Since the SCU code was introduced 2002 with variable uptake among Canadian provinces, study accrual commenced in 2006 to ensure accurate recording of this code. The look back window for assessing patient comorbidities was 3 years.

5.9 Analysis

This thesis focused on patients who had elective non-cardiac surgery given initial pilot data showing important systematic difference observed in patients undergoing emergency surgery. Additionally, an important proportion of emergency surgery patients were admitted to ICU before surgery (n=11270, 7.4% of the emergency surgical group), and a significant proportion of emergency surgery patients were coded as having had trauma at the time of admission (n=88096, 58% of the emergency surgical group).

The main study analyses were therefore performed in the elective surgical group. Since this thesis included comparisons based on hospital-level characteristics (e.g., teaching status), I also excluded data from hospitals that performed very low volumes (fewer than 50 cases over the study period) of individual surgeries, to reduce variability caused by low procedure volumes. The postoperative destination (early ICU, late ICU or general ward) was determined for all elective surgical patients. For each destination, the 30-day and 90-day mortality risks were reported as frequencies (percentages), while lengths of ICU and postoperative stay were described using median (interquartile range).

Descriptive statistics were used to compare perioperative characteristics of patients admitted to ICU early after surgery to those who were initially admitted to a general ward (including a small number who were admitted later to the ICU). Continuous and categorical variables were described using median (interquartile range) and frequency (percentages) respectively. The groups were compared using standardized differences, Wilcoxon Rank Sums test (continuous variables), and Chi-square test (categorical variables).

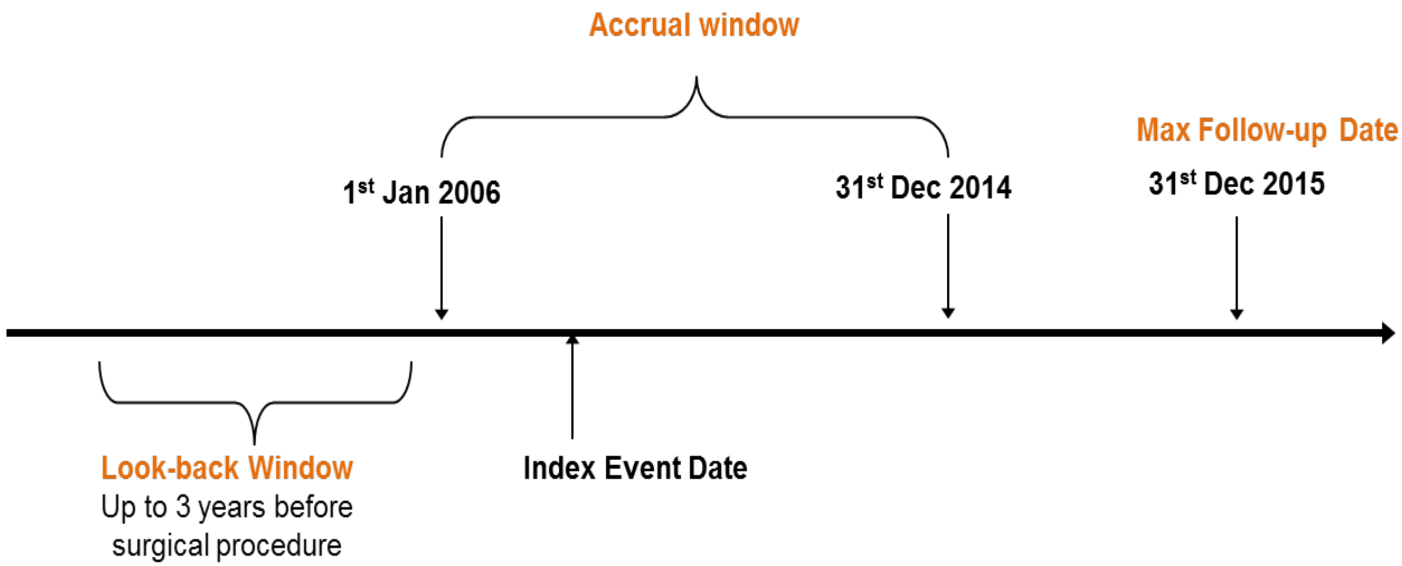
For all and individual surgical groups (AAA, EVAR, peripheral arterial disease, open lung resection, VATS lung resection, upper gastrointestinal, lower gastrointestinal, major urology, major gynecology, neurosurgery, femur, spine, and joint replacement surgery), the unadjusted proportion of patients admitted early to ICU after surgery was calculated for each hospital; hospitals were then ranked based on these proportions. Hospital-specific proportions of patient admitted early to ICU, with associated exact binomial 95% confidence intervals, were plotted for the entire cohort, as well as individual surgical groups. To better understand the extent to which postoperative ICU admission use for different surgical procedures were correlated within individual hospitals, Pearson correlation coefficients were calculated to characterize the association within individual hospitals across different surgery types with respect to the proportions of surgical patients admitted early to ICU. Coefficients < 0.4 were considered low correlation, 0.4-0.7 medium correlation and > 0.7 strong correlation.[52] For each surgical group, I also summarized the postoperative length of stay using median (interquartile range), 30-day and 90-day mortality using frequency (percentages).

Multivariable logistic regression models were then developed separately for each surgical group to characterize the adjusted association of hospital factors (teaching hospital status, proportion of ICU beds, duration of surgery, surgical volume of specific procedure being considered), patient characteristics (age, sex, rurality, Charlson Comorbidity Index score, coronary artery disease, myocardial infarction, chronic renal disease, chronic obstructive pulmonary disease, asthma, primary and secondary malignancy, diabetes, liver disease, hypertension, cerebrovascular disease, atrial fibrillation) with early admission to ICU after surgery. ICU capacity was characterized based on the ratio of ICU beds to total hospital beds, with a 3 knot restricted cubic spline being used to address non-linearity of this hospital-level variable.[53] Age was not assessed for adherence to non-linearity assumptions. The Charlson Comorbidity Index score was categorized as either 0-1 or ≥2. The regression model was estimated using a generalized estimating equation (GEE) to account for hospital-level clustering. An independent correlation structure was applied because models using exchangeable structure did not converge consistently. An independent structure gave stable model estimates with slightly wider confidence intervals. Early ICU admission was modelled using the same covariates listed above for 13 surgical groups (except sex was omitted for modelling hysterectomy surgery). Given that a large number of regression models were developed, Forest plots were used to display the adjusted odds ratios (with associated 95% CI) for individual covariates within models separately developed for the surgical groups. The covariates of interest for which Forest plots are presented include age, sex, teaching status, rurality, surgical volume, duration of surgery, Charlson score and common comorbidities (i.e., asthma, chronic obstructive pulmonary disease, coronary artery disease, hypertension, diabetes).

To better characterize the association of the individual hospital with early admission to ICU, the intra-class correlation coefficient (ICC) and median odds ratio (MOR) were calculated using the estimated variance of the random intercepts from a hierarchical random effects model. This required development of a second multilevel logistic regression model that provides variance estimates of the distribution of the hospital-specific random effects, which cannot be obtained when using a general estimating equation. This hierarchical model assessed the association of the same above patient- and hospital-level covariates (i.e., age, sex, rurality, Charlson Comorbidity Index score, coronary artery disease, myocardial infarction, chronic renal disease, chronic obstructive pulmonary disease, asthma, primary malignancy, secondary malignancy, diabetes, liver disease, hypertension, cerebrovascular disease, atrial fibrillation, hospital teaching status, proportion of ICU beds, duration of surgery, surgical volume of specific procedure being considered) with early ICU admission, while accounting for clustering of patients within individual hospitals. This was performed separately for each of the 13 individual surgical groups. The ICC quantifies the proportion of the total variation in the outcome that is due to systematic differences between admitting hospitals. The MOR is a measure of heterogeneity for use with binary outcomes that expresses inter-hospital variation on an odds ratio scale. After randomly selecting 2 subjects with the same patient-level covariates, the MOR is the median odds ratio obtained when comparing a subject from cluster with a higher risk of early ICU admission against a subject from cluster with a lower risk of early ICU admission.[54] _ENREF_42

Model discrimination and calibration were described using the c-statistic and Loess-based graphical tests of calibration.[55] Significant multi-collinearity between model variables was defined by a variance inflation factor >5. All analyses were conducted using Microsoft Excel (v.2010, Redmond, WA), SAS version 9.4 (SAS Institute, Cary, US) and R statistical software (v.0.98.1091 www.rstudio.org. R Core Team (2014), R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org). Two-sided p-values < 0.05 were considered statistically significant.

Figure 2: Study timeline



6. RESULTS

6.1 Study cohort characteristics

The study cohort consisted of 541,524 patients who underwent 13 elective non-cardiac surgical procedures at 93 Ontario hospitals (Figure 3). The total number of patients admitted to ICU at any time after surgery was 57,251 (10.6%). Early (within 24 hours of surgery) and late (beyond 24 hours after surgery) ICU admission occurred in 52,063 (9.6%) and 5,188 (1.0%) elective surgical patients respectively (Figure 3).

The postoperative discharge destinations for elective surgical patients is summarized in Figure 4. The vast majority of patients (89.4%) were not admitted to an ICU, with an associated 30-day mortality risk of 0.2% and median postoperative length of stay of 4 (IQR 3-5) days. In contrast, patients admitted early to ICU had a 30-day mortality of 2.4% and median postoperative length of stay of 6 (IQR 4-9) days. A total of 2830 (0.5%) patients died within 30 days post-surgery, irrespective of whether they did or did not enter an ICU after surgery (Figure 4). Of these, 964 patients (34.1%) were not admitted at all to an ICU during their hospital stay. Perioperative characteristics of patients admitted early to ICU after surgery versus admitted initially to the ward are described in Tables 1 and 2. A small proportion (1.6%) of patients initially discharged to the ward were later admitted to the ICU more than 24 hours after surgery. Patients admitted to early ICU were generally older with greater number of comorbidities and higher Charlson Comorbidity Index score in comparison to patients initially admitted to the ward. Patients admitted to ICU early after surgery tended to have undergone longer duration surgical procedures, and surgery in teaching and larger hospitals (i.e., higher number of hospital beds, surgical beds and ICU beds). As anticipated for a sicker patient group, the unadjusted postoperative length of stay, short and longer-term mortality risk were significantly higher among the early ICU cohort (Table 2). Although late ICU admissions represented a relatively small subgroup, they had much higher risks of 30-day (11.6% vs. 2.4%) and 90-day (15.8% vs. 4.2%) mortality, with a longer associated postoperative length of stay (13 vs. 6 days), when compared to early ICU admissions (Figure 4).

6. 2 Variation and factors affecting early ICU admission

In the cohort of all 541,524 elective surgical procedures, the median hospital-specific proportion of patients admitted to ICU early after surgery was 8.2% (IQR 5.3-13.0) across the 93 included Ontario hospitals. The median hospital-specific percentage of patients admitted early to ICU after surgery for each individual surgical group is summarized in Table 3. The overall median hospital-specific proportion of patients admitted early to ICU was highest among open AAA repair (90.8%), followed by neurosurgery (60.3%), open lung resection (58.4%), VATS lung resection (52.8%), upper gastrointestinal (39.1%), EVAR (19.3%), lower gastrointestinal (10.2%), nephrectomy (9.8%), peripheral arterial disease (9.2%), femur (7.3%), spine (4.7%), joint replacement (1.6%) and hysterectomy (0.9%) surgeries. The variation in hospital-specific rates of early ICU admission for all surgeries and individual groups is shown in Figure 5. In the case of open AAA repair, lung resection and neurosurgery, many hospitals showed high rates of early ICU admission. The remaining surgical groups showed generally lower rates and wide inter-hospital variation in rates of early ICU admission.

There was generally poor within-hospital correlation in the probabilities of early ICU admission across different surgical groups (Figure 6). In generally, there was positive correlation of low-medium magnitude. However, stronger correlations were evident among surgical types that were performed by similar types of surgeons. Examples included lower and upper gastrointestinal surgery (typically performed by general surgeons); spine, femur and joint replacement surgery (typically performed by orthopedic surgeons); and EVAR and peripheral arterial disease surgery (typically performed by vascular surgeons). High coefficients were also present between other surgical groups such as hysterectomy, femur and spine surgery.

This considerable variation between surgeries with respect to hospital-specific practices of early ICU admission justified the decision to model the risk of early ICU admission separately for each surgical group using a GEE multilevel logistic regression model (see Section 5.6). The adjusted odds ratios describing the association of patient, surgery and hospital factors with early ICU admission for each surgical group are summarized in Figure 7 and Table C1 (Appendix C). The Forest plots in Figure 7 communicate the range of OR estimates across different surgical groups. The adjusted association of individual covariates with early ICU admission across the different surgical groups is described below.

Patient demographics – Increasing patient age was associated with an increased risk of early ICU admission for lung, open AAA, upper gastrointestinal, lower gastrointestinal, nephrectomy, femur and hysterectomy surgeries. Age was not associated with early ICU admission for the other surgical groups. Sex was generally not associated with early ICU admission across surgical groups except joint replacement, in which there were higher odds of admission in men. A rural location was associated with an increased risk of early ICU admission in lower gastrointestinal surgery, but reduced odds for EVAR and spinal surgery.

Patient comorbidities – In the case of surgical procedures that generally admitted fewer patients to the ICU, such as lower gastrointestinal surgery, nephrectomy, hysterectomy, joint replacement, spine and femur surgery, a Charlson score ≥ 2 was associated with an increased odds of early ICU admission. Among procedures with generally higher rates of early ICU admission (neurosurgery, aortic and lung surgery), the Charlson score was associated with increased odds of early admission only in the case of VATS lung resection. Presence of comorbidities (i.e., coronary artery disease, hypertension, asthma, diabetes and chronic obstructive pulmonary disease, atrial fibrillation, chronic kidney disease) display a similar pattern with an increased odds of early ICU admission among surgical procedures that admit fewer patients (Figure 7, Table C1).

Surgical characteristics - Increased duration of surgery was associated with a higher odds of early ICU admission for all surgical groups, except in open lung resection and open AAA repair where there was no difference. The point estimates for these odds ratios exceeded 1 for both open AAA (1.02, 95% CI 0.99-1.05) and open lung resection (1.02, 95% CI 0.99-1.05), suggesting that the lack of statistically significant association was due in part to an insufficient sample size. Volume of individual surgical procedures was generally not associated with early ICU admission, except for higher volumes of open AAA being associated with lower risk of early ICU admission.

Hospital characteristics – In comparison to community hospitals, academic institutions showed no association with the odds of early ICU admission, except for a reduced risk being seen in the upper gastrointestinal surgical group. The nature of the relationship between ICU bed capacity and the risk of early ICU admission was highly variable across surgical groups, with no consistent pattern of relationship being observed (Figure 8).

Loess plots demonstrate that most models displayed reasonable calibration except at higher predicted probabilities for hysterectomy and joint replacement surgery (Figure 9). Good model discrimination assessed using the c-statistic with no multi-collinearity was seen (Table 4).

6.3 Quantifying between-hospital variation in early ICU admission

The association of the individual admitting institution on the odds of early ICU admission was characterized separately for all surgical groups using the ICC and MOR. In all surgical groups, the admitting institution was a strong factor affecting ICU admission (Table 5). The ICC values ranged between 18% for hysterectomy to 75.9% for EVAR, and MOR values ranged from 2.3 to 21.5.

Figure 3: Assembly of study cohort

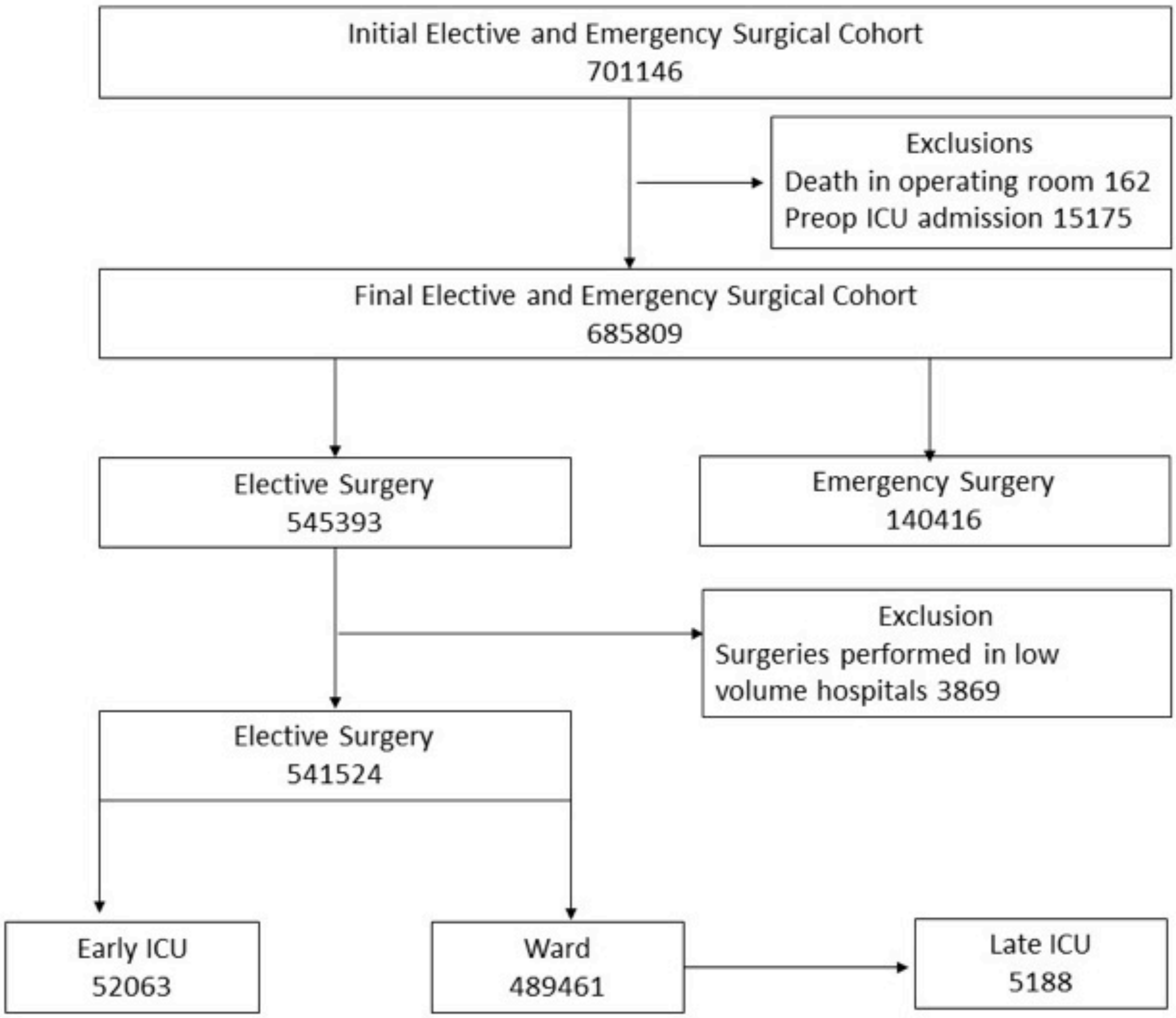
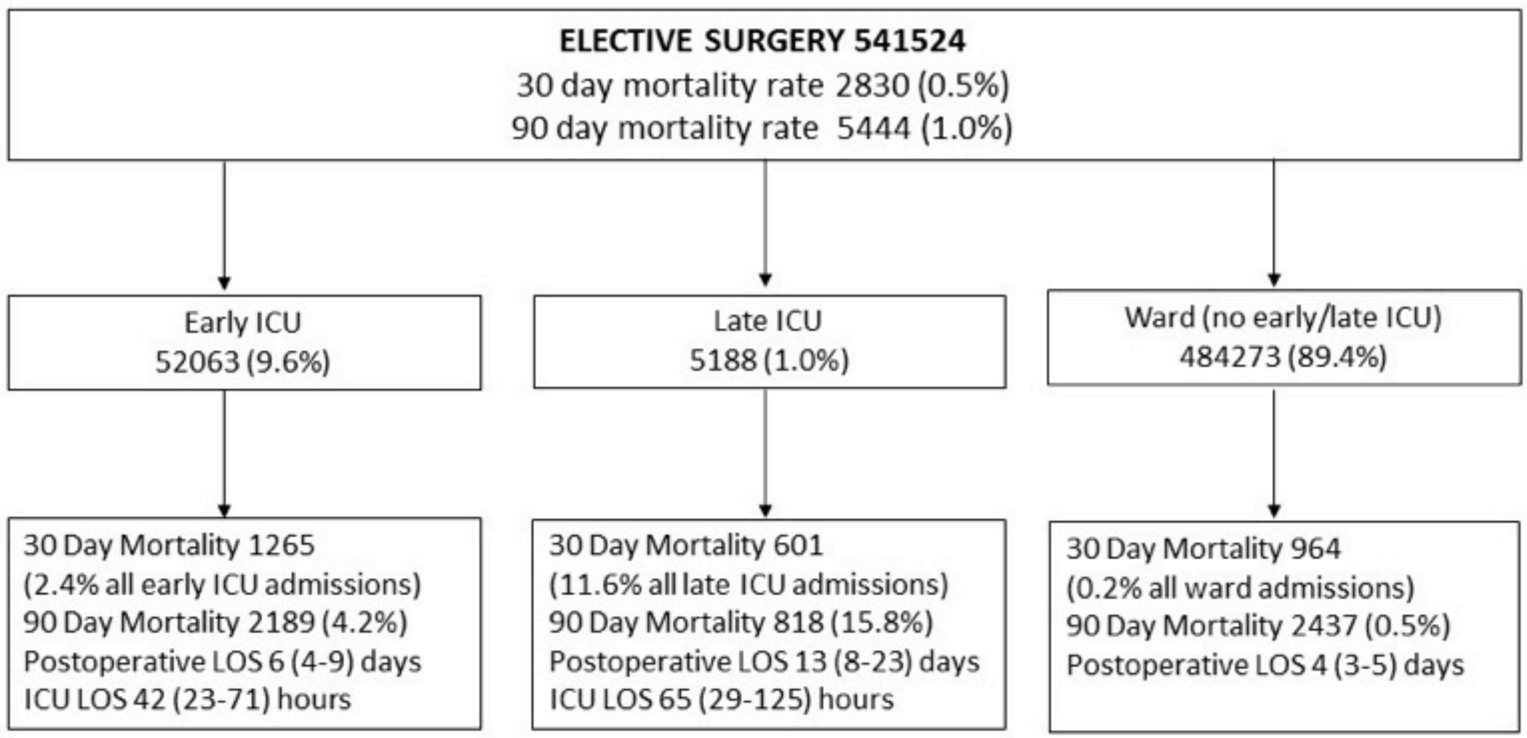


Figure 4: Postoperative destinations and mortality risks within strata defined by postoperative ICU use for elective major non-cardiac surgery patients.

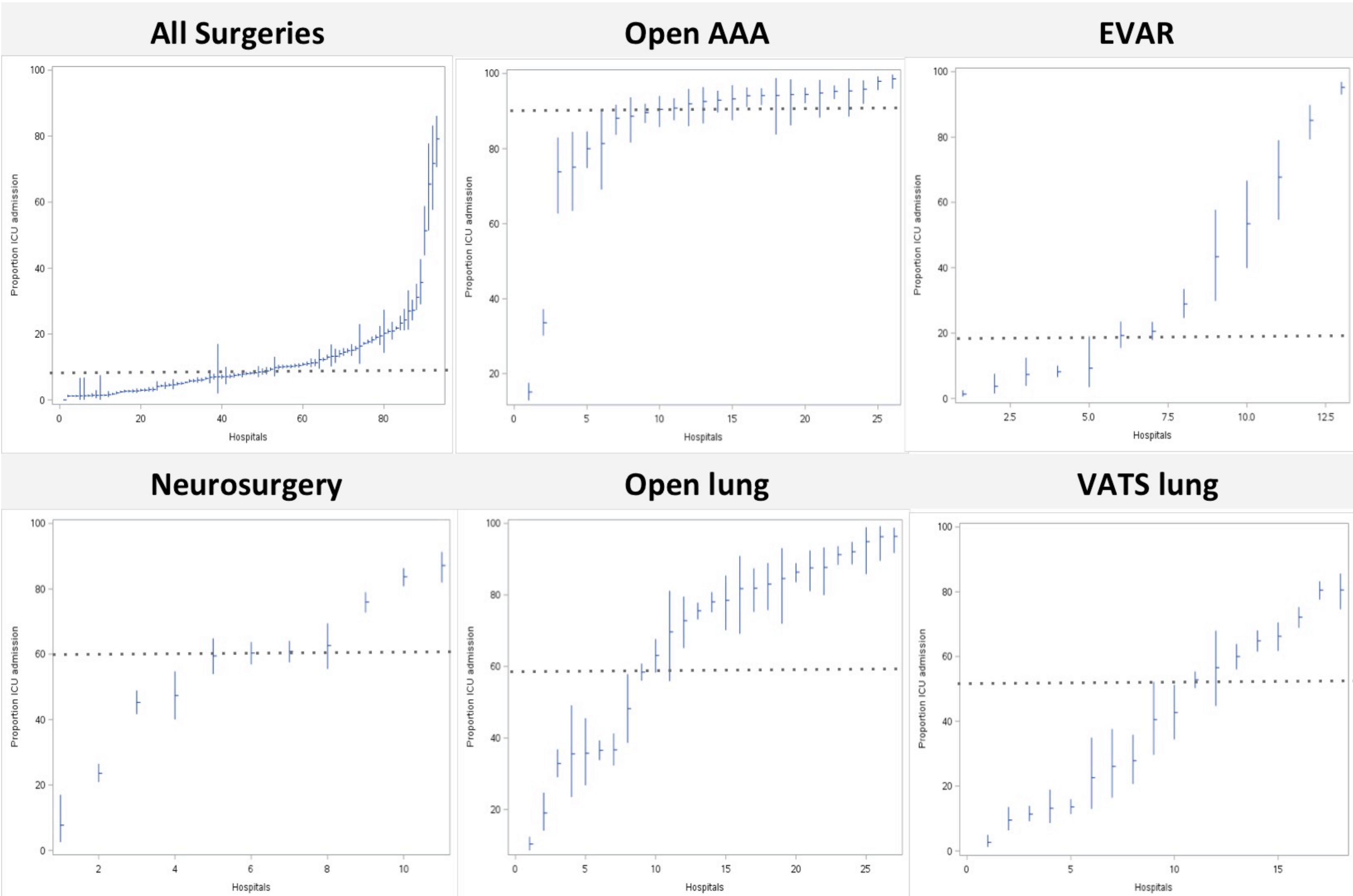


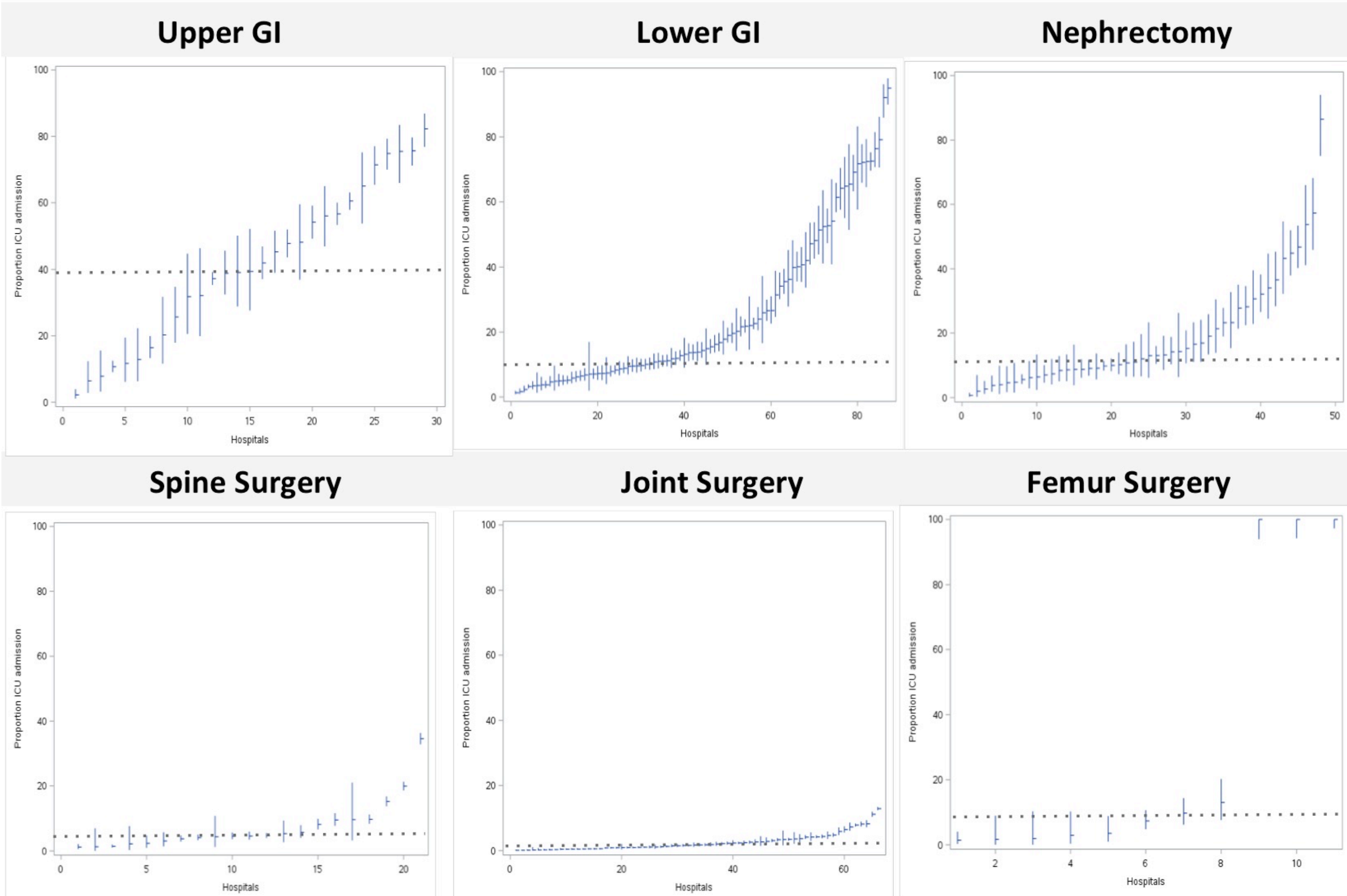
POSTOPERATIVE 30 AND 90 DAY MORTALITY RATES STRATIFIED ACCORDING TO ICU EXPOSURE

	30 Day Mortality (N=2830)	90 Day Mortality (N=5444)
Early ICU	1265 (44.7%)	2189 (40.2%)
Late ICU	601 (21.2%)	818 (15.0%)
No ICU Admission	964 (34.1%)	2437 (44.8%)

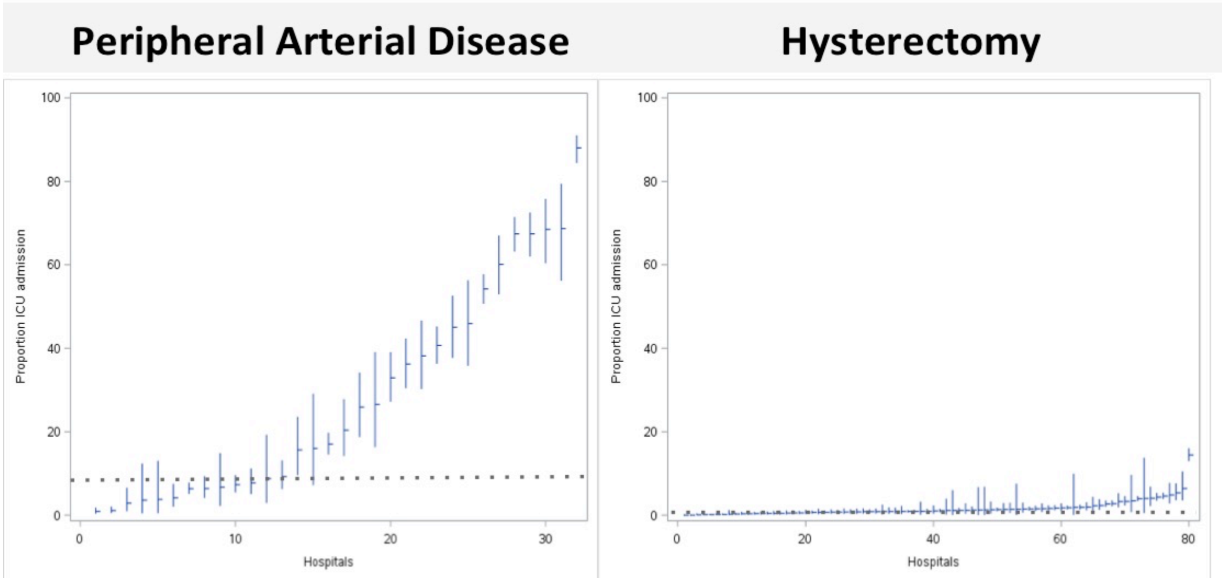
Numbers given as n(%), median (interquartile range). LOS Length of stay; ICU Intensive care unit

Figure 5: Hospital-specific proportions with early ICU postoperative admission separately presented for each surgical group. Each bar represents point estimate and exact binomial 95% confidence interval. Dotted line represents the median hospital-specific proportion of early ICU admission.



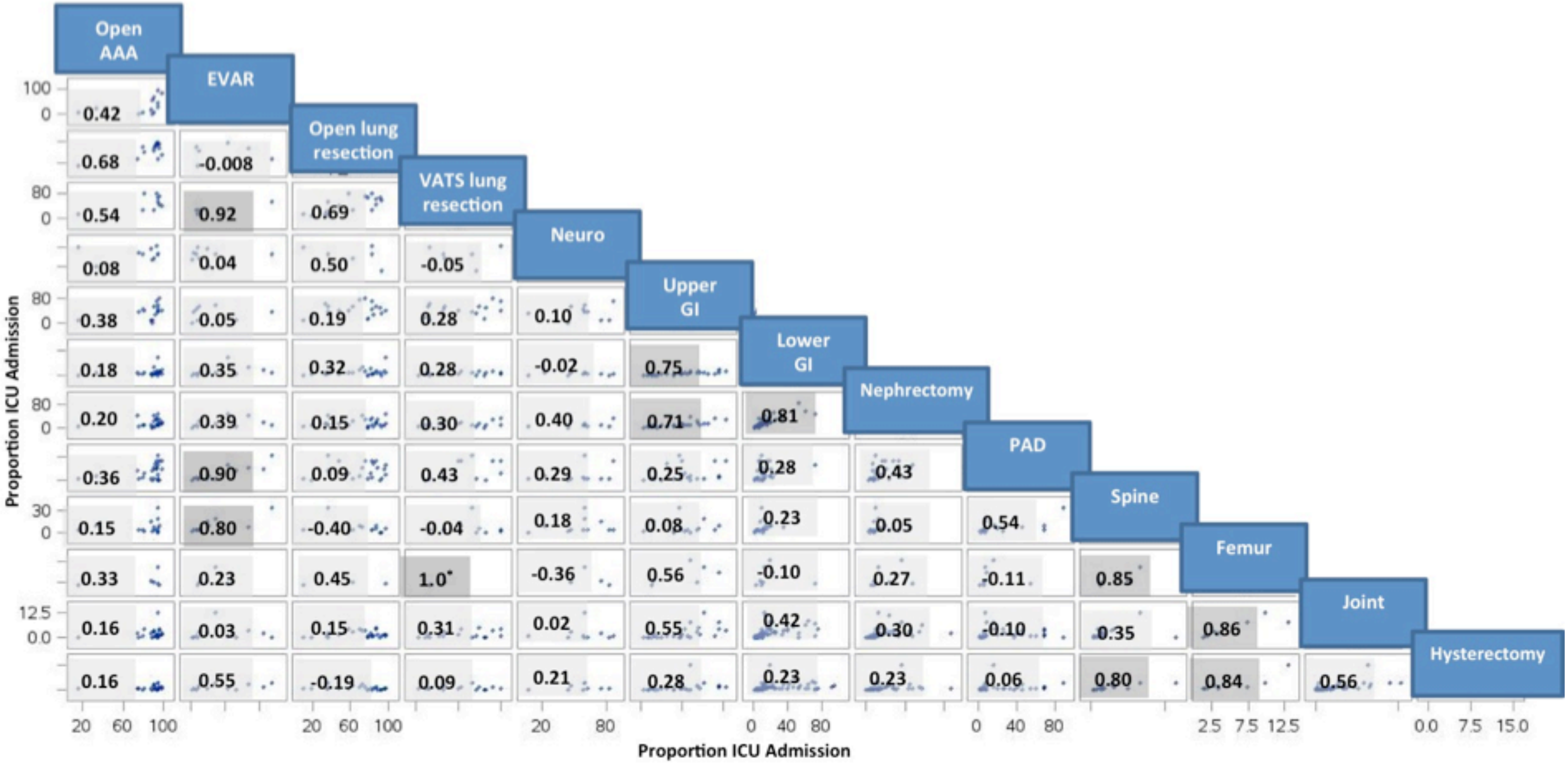


Upper GI
Lower GI
Nephrectomy
Spine Surgery
Joint Surgery
Femur Surgery
Proportion ICU admission
Hospitals



AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; ICU Intensive care unit; VATS Video assisted thoracic surgery

Figure 6: Matrix describing the within-hospital correlation in proportions of patients with early ICU admission across different surgical procedures.



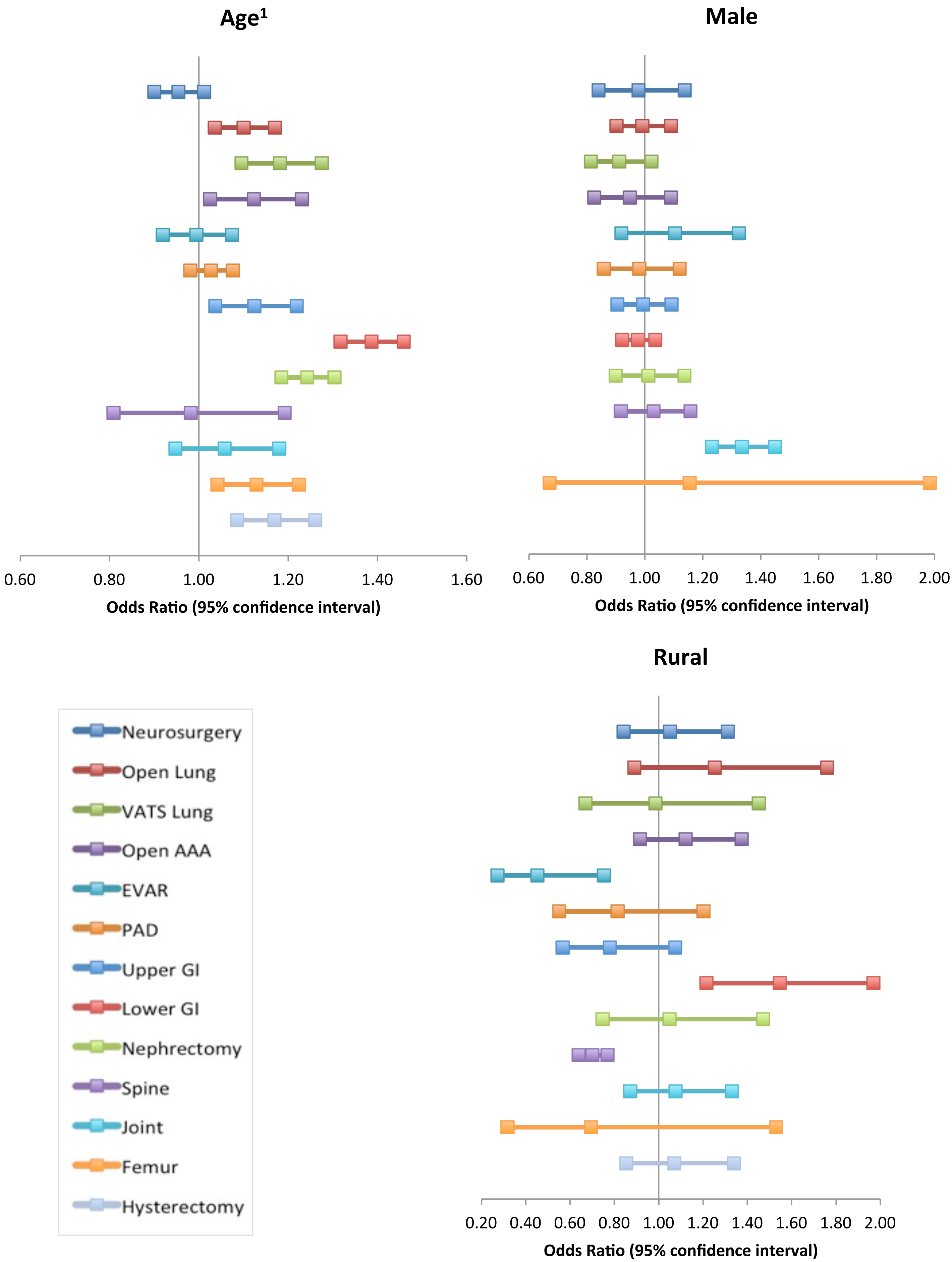
*Correlation coefficient based on 2 hospitals

AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; PAD Peripheral arterial disease; ICU Intensive care unit; VATS Video assisted thoracic surgery

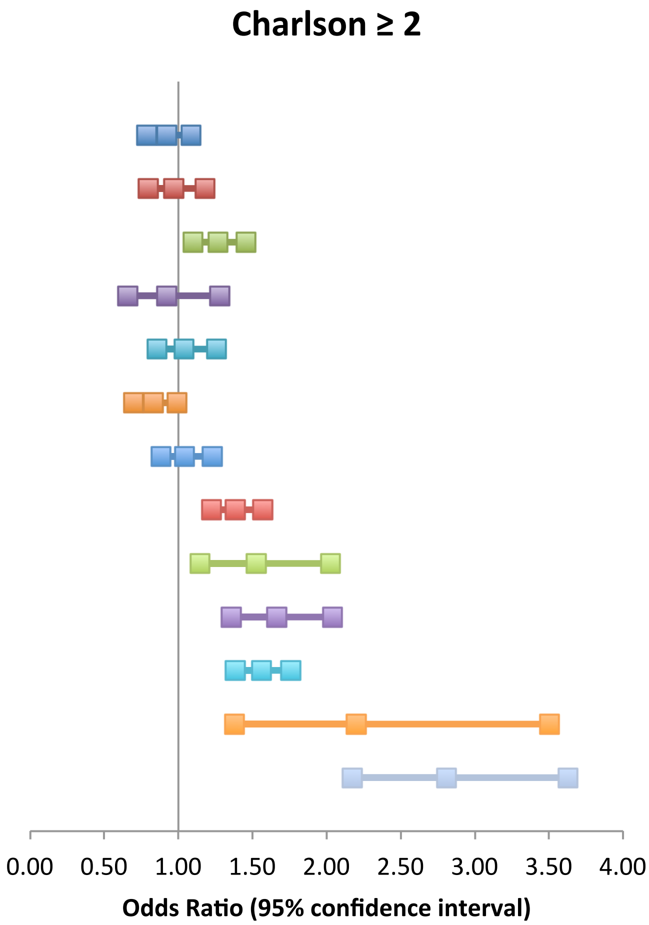
Figure 7: Forest plots summarizing the adjusted association of various covariates with early ICU admission across different surgical groups.

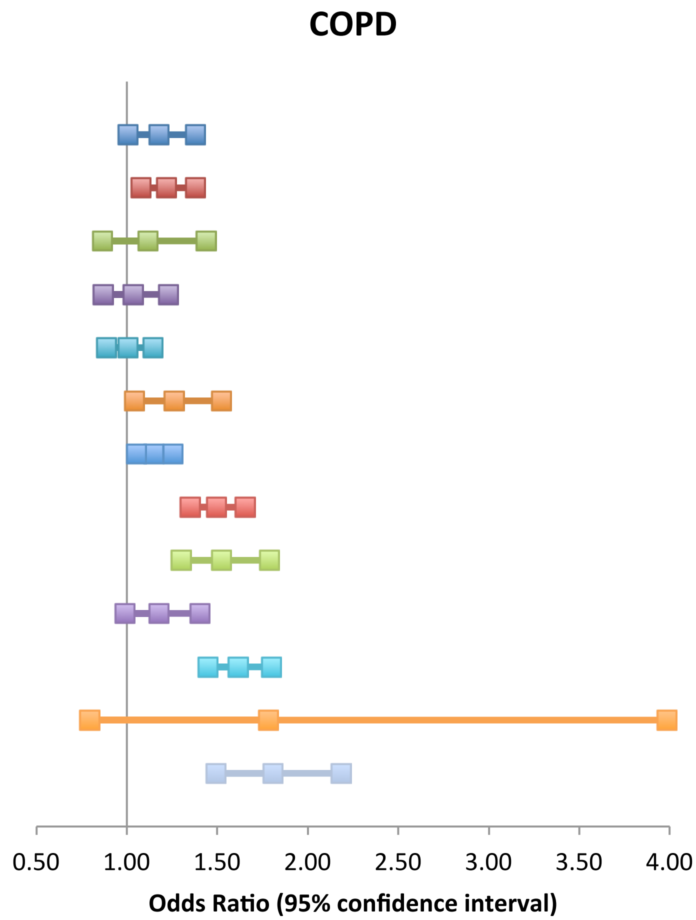
[1]Age Odds Ratio (95% confidence interval) for every 10 years
[2]Duration Surgery Odds Ratio (95% confidence interval) for every 10 minutes

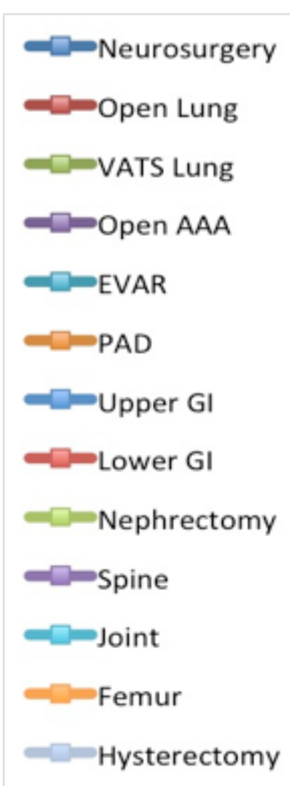
AAA Abdominal aortic aneurysm; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; ICU Intensive care unit; PAD Peripheral arterial disease; VATS Video assisted thoracic surgery

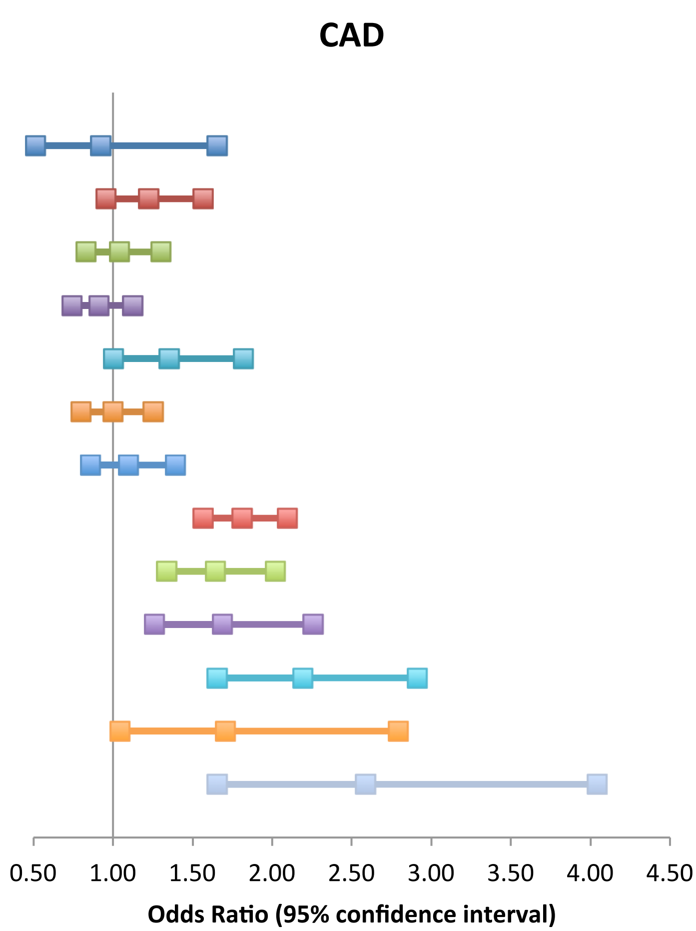


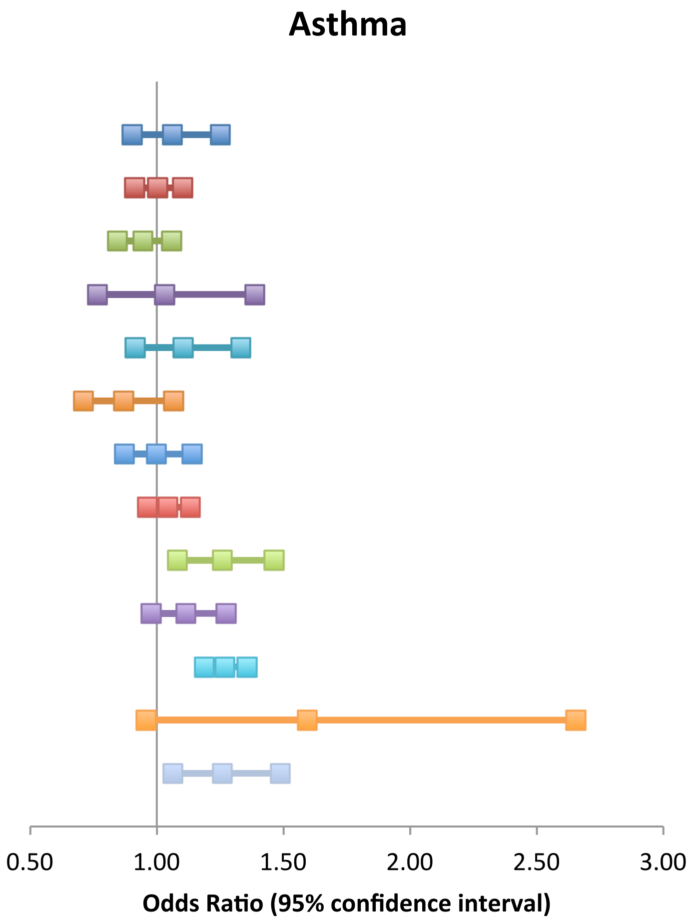
Age[1]
0.60
0.80
1.00
1.20
1.40
1.60
Odds Ratio (95% confidence interval)
Male
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Odds Ratio (95% confidence interval)
Rural
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Odds Ratio (95% confidence interval)
Neurosurgery
Open Lung
VATS Lung
Open AAA
EVAR
PAD
Upper GI
Lower GI
Nephrectomy
Spine
Joint
Femur
Hysterectomy

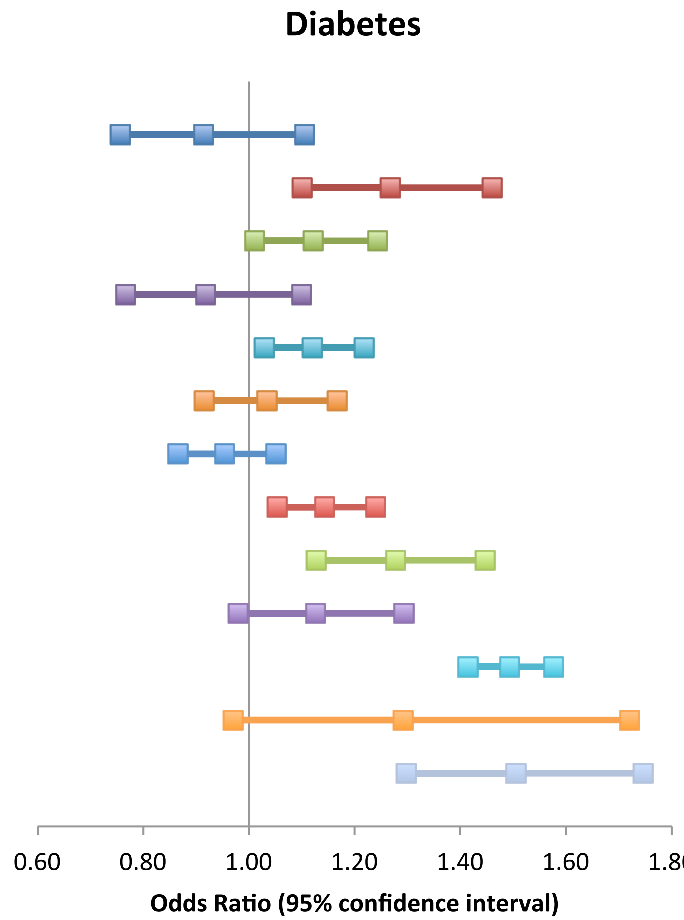

Charlson ≥ 2
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00
Odds Ratio (95% confidence interval)

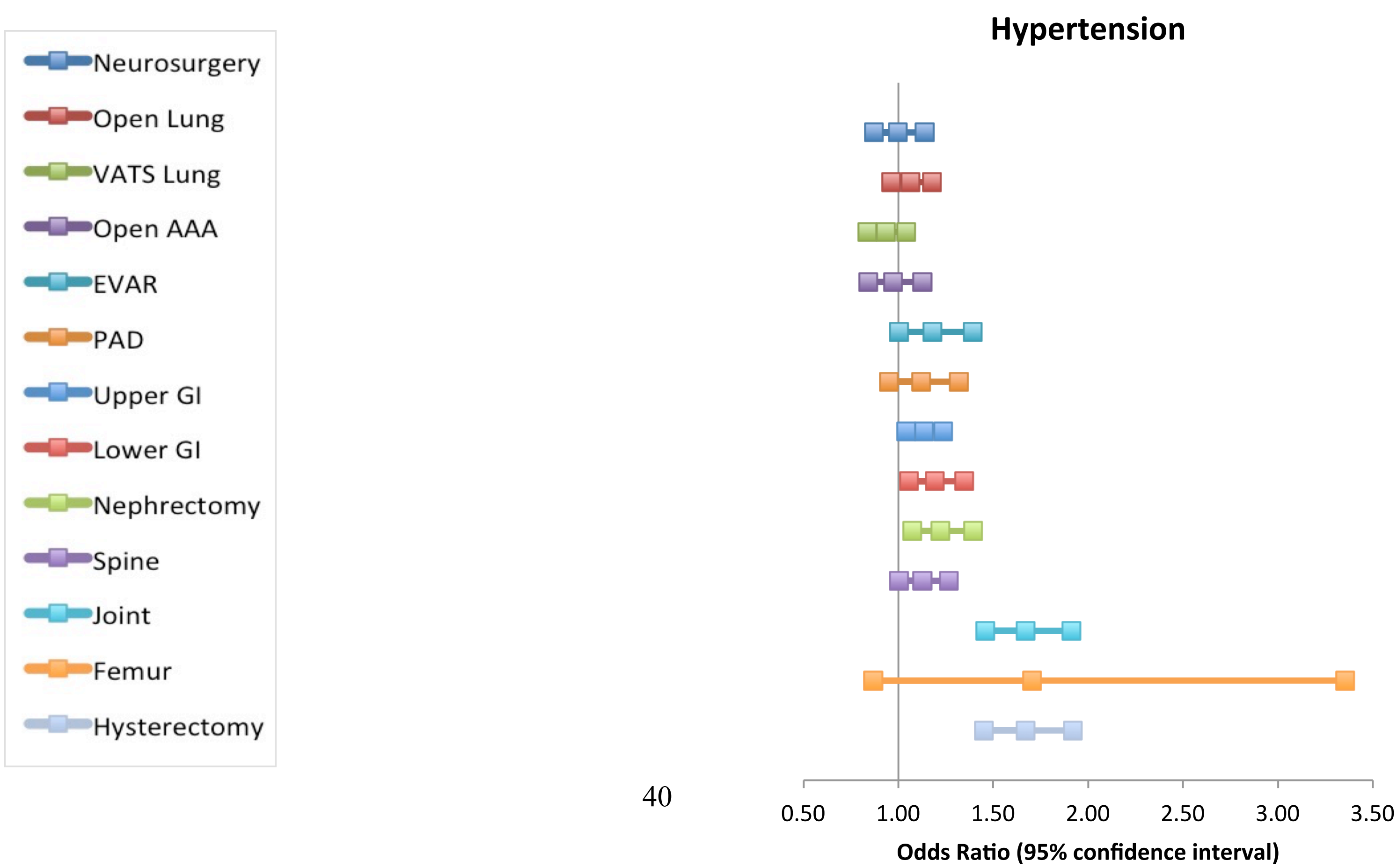

COPD
0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00
Odds Ratio (95% confidence interval)


Neurosurgery
Open Lung
VATS Lung
Open AAA
EVAR
PAD
Upper GI
Lower GI
Nephrectomy
Spine
Joint
Femur
Hysterectomy


CAD
0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50
Odds Ratio (95% confidence interval)


Asthma
0.50
1.00
1.50
2.00
2.50
3.00
Odds Ratio (95% confidence interval)


Diabetes
0.60
0.80
1.00
1.20
1.40
1.60
Odds Ratio (95% confidence interval)


Neurosurgery
Open Lung
VATS Lung
Open AAA
EVAR
PAD
Upper GI
Lower GI
Nephrectomy
Spine
Joint
Femur
Hysterectomy
Hypertension
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Odds Ratio (95% confidence interval)

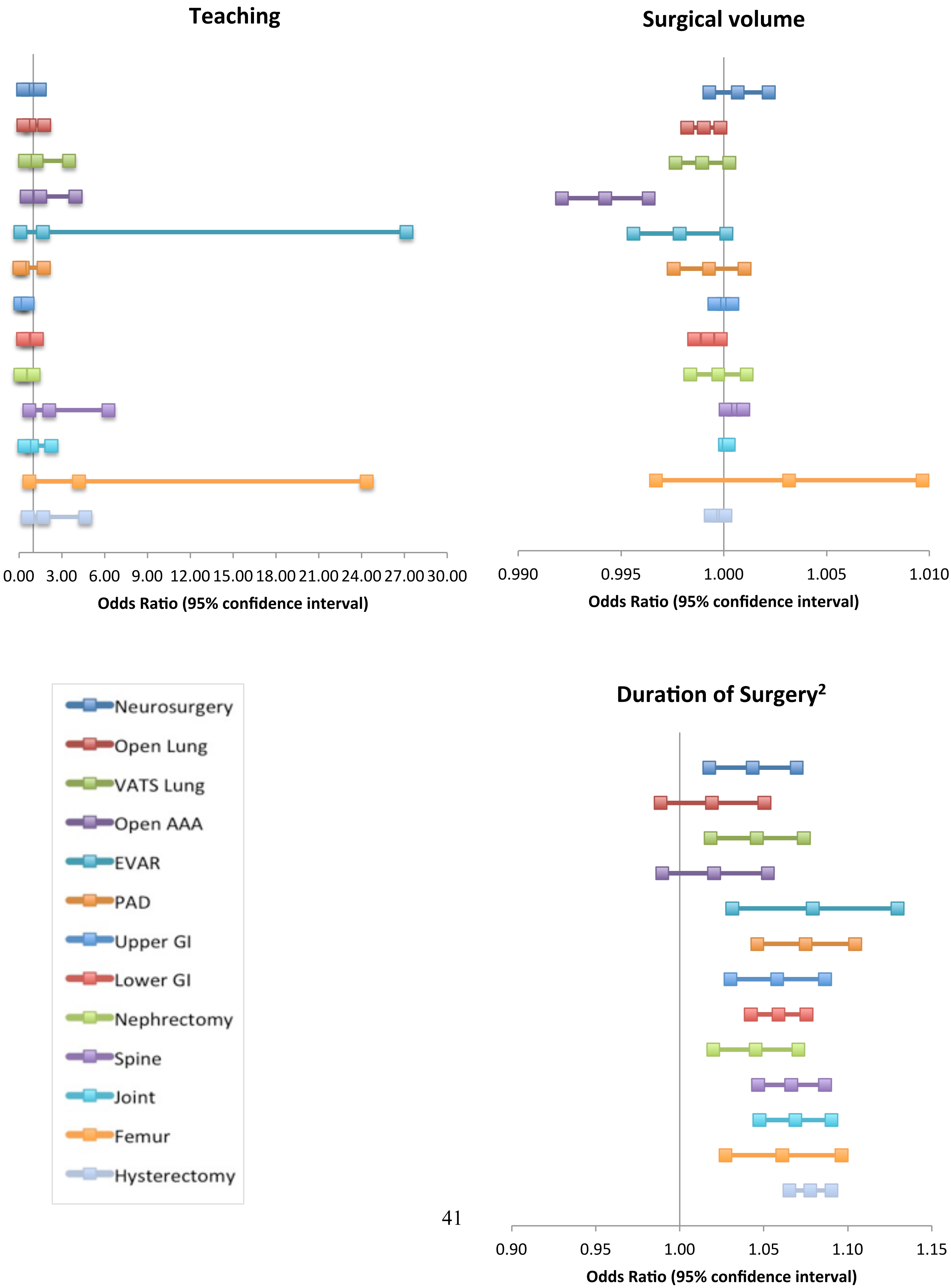
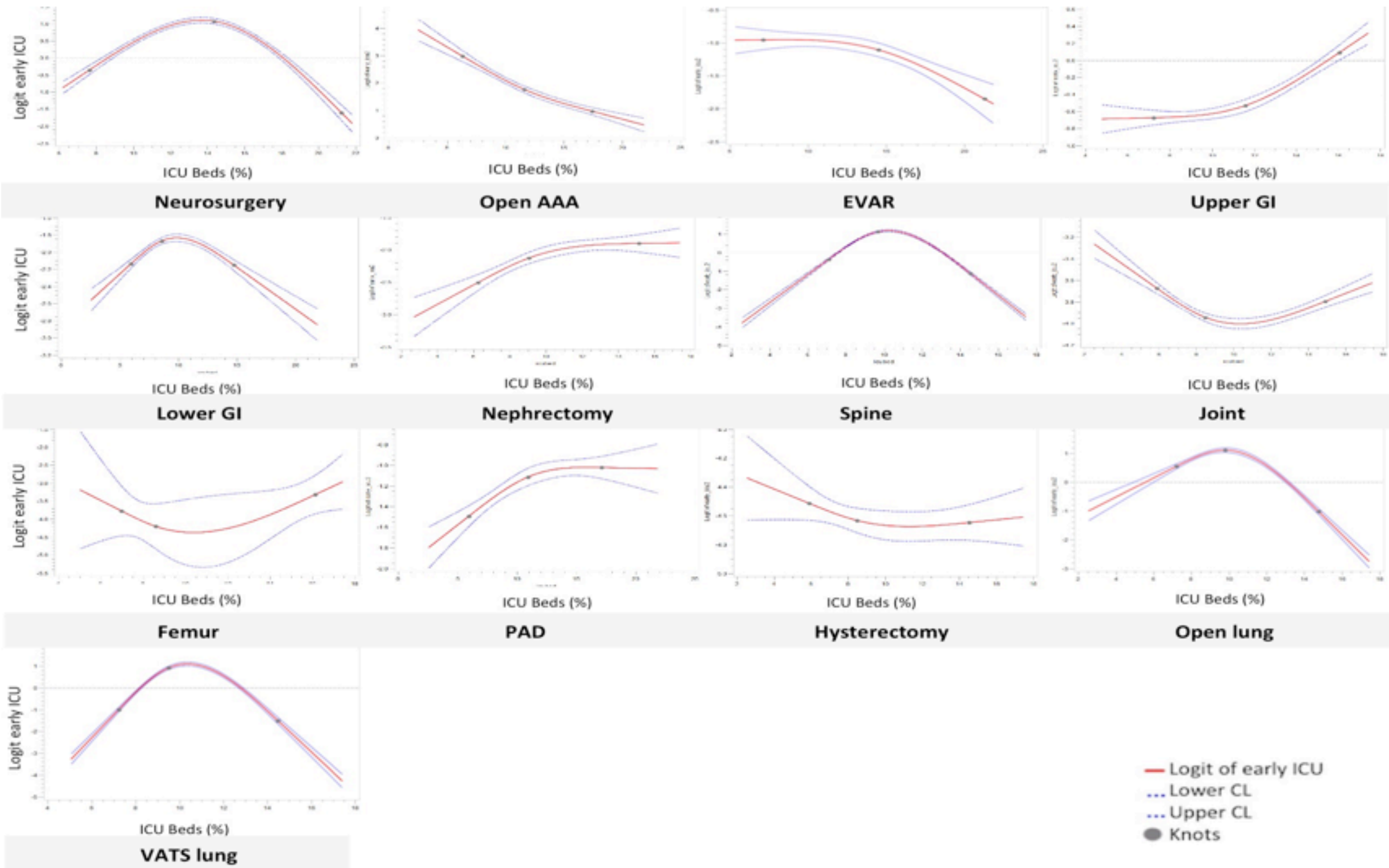
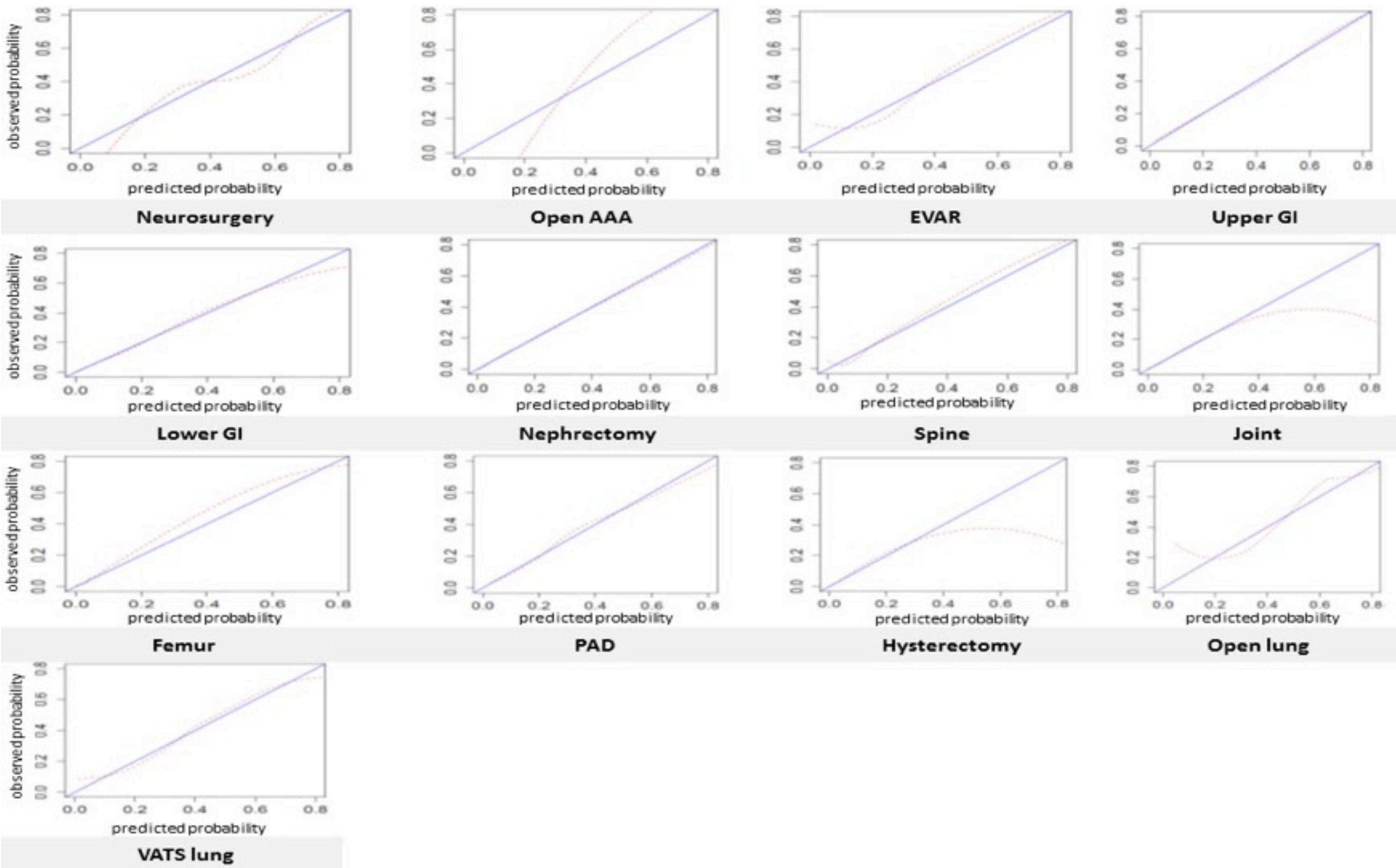

Teaching
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
Odds Ratio (95% confidence interval)
Surgical volume
0.990
0.995
1.000
1.005
1.010
Odds Ratio (95% confidence interval)
Neurosurgery
Open Lung
VATS Lung
Open AAA
EVAR
PAD
Upper GI
Lower GI
Nephrectomy
Spine
Joint
Femur
Hysterectomy
Duration of Surgery²
0.90
0.95
1.00
1.05
1.10
1.15
Odds Ratio (95% confidence interval)

Figure 8: Adjusted association of hospital-specific ICU bed availability (expressed as the percentage of total hospital beds represented by ICU beds) with early ICU admission for each elective surgical group – modeled using restricted cubic splines.



AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; PAD Peripheral arterial disease; VATS Video assisted thoracic surgery; ICU Intensive care unit

Figure 9: Loess calibration plots for logistic regression models predicting early ICU admission. Each model's calibration (red line) can be viewed over a wide range of predicted probabilities and compared to perfect calibration (blue line).*



**Logistic regression models estimated using a general estimating equation*

AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; PAD Peripheral arterial disease; VATS Video assisted thoracic surgery

Table 1: Patient characteristics of early versus no early ICU admission after elective surgery.

Variable	No Early ICU (N=489,461)	Early ICU (N=52,063)	Total (N=541,524)	Standardized Difference	P-value
Age (yr)	65 (55-73)	68 (60-76)	65 (55-74)	0.28	<.001
Female	315,470 (64.5%)	23,355 (44.9%)	338,825 (62.6%)	0.40	<.001
Atrial fibrillation	11,105 (2.3%)	3,343 (6.4%)	14,448 (2.7%)	0.20	<.001
CAD	17,318 (3.5%)	5,514 (10.6%)	22,832 (4.2%)	0.28	<.001
Hypertension	299,201 (61.1%)	36,874 (70.8%)	336,075 (62.1%)	0.21	<.001
Myocardial infarction	6,702 (1.4%)	2,300 (4.4%)	9,002 (1.7%)	0.18	<.001
PVD	6,652 (1.4%)	3,703 (7.1%)	10,355 (1.9%)	0.29	<.001
Stroke	4,301 (0.9%)	1,282 (2.5%)	5,583 (1.0%)	0.12	<.001
Diabetes	109,081 (22.3%)	16,061 (30.8%)	125,142 (23.1%)	0.19	<.001
Asthma	75,283 (15.4%)	8,436 (16.2%)	83,719 (15.5%)	0.02	<.001
COPD	85,541 (17.5%)	17,700 (34.0%)	103,241 (19.1%)	0.38	<.001
Chronic renal disease	4,183 (0.9%)	1,425 (2.7%)	5,608 (1.0%)	0.14	<.001
Dialysis	1,382 (0.3%)	446 (0.9%)	1,828 (0.3%)	0.08	<.001
Chronic liver disease	1,738 (0.4%)	572 (1.1%)	2,310 (0.4%)	0.09	<.001
Primary Cancer	21,454 (4.4%)	8,646 (16.6%)	30,100 (5.6%)	0.41	<.001
Secondary Cancer	15,948 (3.3%)	5,949 (11.4%)	21,897 (4.0%)	0.32	<.001
Charlson Score ≥2	50,702 (10.4%)	17,231 (33.1%)	67,933 (12.5%)	0.57	<.001
Rural residence	76,183 (15.6%)	7,882 (15.1%)	84,065 (15.5%)	0.01	0.011

CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; ICU Intensive care unit; PVD Peripheral vascular disease
Numbers reported as n (%) and median (interquartile range)

Table 2: Patient outcomes, surgical characteristics, and hospital characteristics of early versus no early ICU admission after elective surgery.

Variable	No Early ICU (N=489,461)	Early ICU (N=52,063)	Total (N=541,524)	Standardized Difference	P-value
SURGERY					
Open AAA	1,734 (0.4%)	5,692 (10.9%)	7,426 (1.4%)	0.47	<.001
EVAR	3,432 (0.7%)	1,253 (2.4%)	4,685 (0.9%)	0.14	
Femur	1,378 (0.3%)	74 (0.1%)	1,452 (0.3%)	0.03	
Hysterectomy	102,063 (20.9%)	1,634 (3.1%)	103,697 (19.1%)	0.57	
Joint	271,519 (55.5%)	8,654 (16.6%)	280,173 (51.7%)	0.88	
Lower GI	48,188 (9.8%)	9,195 (17.7%)	57,383 (10.6%)	0.23	
Nephrectomy	11,056 (2.3%)	1,714 (3.3%)	12,770 (2.4%)	0.06	
Upper GI	6,630 (1.4%)	4,710 (9.0%)	11,340 (2.1%)	0.35	
Open lung resection	4,444 (0.9%)	6,336 (12.2%)	10,780 (2.0%)	0.47	
VATS lobectomy	4,334 (0.9%)	3,843 (7.4%)	8,177 (1.5%)	0.33	
Neurosurgery	2,485 (0.5%)	3,366 (6.5%)	5,851 (1.1%)	0.33	
PAD	7,789 (1.6%)	2,668 (5.1%)	10,457 (1.9%)	0.2	
Spine	24,409 (5.0%)	2,924 (5.6%)	27,333 (5.0%)	0.03	
Duration Surgery (min)	123 (98-166)	205 (140-287)	127 (100-178)	0.9	<.001
HOSPITAL					
Teaching hospital	176,521 (36.1%)	24,801 (47.6%)	201,322 (37.2%)	0.24	<.001
Total beds	277 (192-355)	305 (219-447)	284 (196-360)	0.27	<.001
Surgical Beds	68 (45-125)	85 (55-170)	70 (45-127)	0.27	<.001
ICU beds	21 (14-40)	27 (18-64)	22 (14-49)	0.34	<.001
Proportion ICU beds	9 (7-12)	10 (7-13)	9 (7-12)	0.28	<.001
OUTCOMES					
30 day MR	1,565 (0.3%)	1,265 (2.4%)	2,830 (0.5%)	0.18	<.001
90 day MR	3,255 (0.7%)	2,189 (4.2%)	5,444 (1.0%)	0.23	<.001
Postoperative LOS	4 (3-5)	6 (4-9)	4 (3-5)	0.81	<.001

AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; ICU Intensive care unit; LOS Length of stay; MR Mortality rate; PAD Peripheral arterial disease; VATS Video assisted thoracic surgery. Numbers reported as n (%) and median (interquartile range).

Table 3: Postoperative length of stay and mortality for patients who had 13 selected elective surgical procedures.

Surgery Type	Hospital-Specific Proportion of Early ICU Admission, % Median (IQR)	Total Volume of Surgical procedures*	Number Hospitals	Postoperative LOS, days Median (IQR)	30 Day mortality	90 Day mortality
All Surgeries+	8.2 (5.3-13.0)	541524	93	4 (3-5)	2830 (0.5%)	5444 (1.0%)
Open AAA	90.8 (80.0-94.4)	7426	26	7 (6-9)	184 (1.9%)	258 (3.5%)
EVAR	19.3 (8.1-28.9)	4685	13	2 (1-4)	48 (1.0%)	92 (2.0%)
Open lung	58.4 (36.6-78.1)	10780	27	6 (4-8)	203 (1.9%)	409 (3.8%)
VATS lung	52.8 (13.5-66.2)	8177	18	3 (2-5)	62 (0.8%)	143 (1.8%)
Neurosurgery	60.3 (45.2-76.0)	5851	11	3 (2-6)	146 (2.5%)	485 (8.3%)
Upper GI	39.1 (25.7-60.5)	11340	29	8 (6-11)	231 (2.0%)	442 (3.9%)
Lower GI	10.2 (6.2-19.0)	57383	87	6 (4-9)	835 (1.5%)	1361 (2.4%)
Nephrectomy	9.8 (7.0-14.2)	12770	48	4 (3-6)	94 (0.7%)	196 (1.5%)
Spine	4.7 (4.1-15.2)	27333	21	3 (2-6)	86 (0.3%)	178 (0.7%)
Joint surgery	1.6 (0.8-4.2)	280173	66	4 (3-5)	574 (0.2%)	1072 (0.4%)
Femur	7.3 (1.9-9.7)	1452	11	5 (3-8)	41 (2.8%)	99 (6.8%)
PAD	9.2 (6.3-45.1)	10457	32	5 (3-8)	218 (2.1%)	460 (4.4%)
Hysterectomy	0.9 (0.5-1.8)	103697	80	3 (2-3)	108 (0.1%)	249 (0.2%)

**Total number of patients over the entire time frame of the study*

+ All 13 surgical groups are combined into this row

AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; GI Gastrointestinal; ICU Intensive care unit; LOS Length of stay; PAD Peripheral arterial disease; VATS Video assisted thoracic surgery

Table 4: Model discrimination assessed using the concordance (C) statistic for each surgical group.*

Surgical Group	C-statistic
Open AAA	0.84
EVAR	0.74
Neurosurgery	0.75
Open lung	0.73
VATS lung	0.76
Upper gastrointestinal	0.74
Lower gastrointestinal	0.76
Nephrectomy	0.74
Spine	0.78
Joint	0.75
Femur	0.83
Peripheral arterial disease	0.75
Hysterectomy	0.77

***Logistic regression models estimated using a general estimating equation*
AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; VATS Video assisted thoracic surgery

Table 5: Intra-class correlation coefficients (ICC) and median odds ratios (MOR) quantifying the relative contribution of the individual hospital to patients' odds of early postoperative ICU admission, separately determined for each surgical group.

Surgery Type	Estimated variance of the random effect	ICC (%)	MOR
Open AAA	3.9794	54.7	6.7
EVAR	10.3420	75.9	21.5
Open lung	2.8342	46.3	5.0
VATS lung	2.1129	39.1	4.0
Neurosurgery	1.8939	36.5	3.7
Upper Gastrointestinal	1.0863	24.8	2.7
Lower Gastrointestinal	1.8358	35.8	3.6
Nephrectomy	1.5279	31.7	3.3
Spine	0.7969	19.5	2.3
Joint surgery	1.4737	30.9	3.2
Femur	2.5571	43.7	4.6
PAD	3.3454	50.4	5.7
Hysterectomy	0.7236	18.0	2.3

AAA Abdominal aortic aneurysm; EVAR Endovascular abdominal aortic aneurysm repair; VATS Video assisted thoracic surgery

7. DISCUSSION

This thesis examined ICU admission early after major elective non-cardiac surgery with respect to its overall utilization, inter-hospital variation and predictive factors. When all surgeries are considered collectively, approximately twice as many elective surgical patients in Ontario are admitted to ICU in the early postoperative period compared with centres in the European Surgical Outcomes (EUSOS) Study (9.6% vs. 5%). The 30-day mortality in patients admitted to ICU is similar to the in-hospital mortality reported in the EUSOS study (2.4% vs. 2%) although the ICU length of stay is slightly longer in Ontario (42 hours vs. 1 day).[21] However, the proportion of patients admitted to ICU early after elective non-cardiac surgery in Ontario is comparable to the global average (9.7%) seen in the recent International Surgical Outcomes Study (ISOS) conducted in 44,814 patients across 27 countries including North America, Europe, Australia, Brazil, China and Africa.[11] Most patients in Ontario were initially admitted to a surgical ward after major elective non-cardiac surgery, with the proportion of patients being admitted later to the ICU similar to the proportion seen in the EUSOS study (approximately 1%). The higher early ICU admission rates observed in Ontario is likely due to greater access and ICU bed capacity compared with many countries included in the EUSOS study.[21] The median (interquartile range) number of ICU beds per hospital is slightly higher in Ontario at 22 (14-49) compared to 19 (9-40) beds in European centres.[21]

These data also identified wide variations in the rates of postoperative ICU admission in Ontario for the 13 surgical groups examined. Across all the surgeries evaluated, the individual admitting hospital was the strongest factor influencing the risk of early ICU admission, and accounted for a large proportion of the observed inter-hospital variation. It was largely in surgical procedures with generally lower rates of early ICU admission (general, orthopedic and uro-gynecological procedures) where selection of patients for postoperative ICU admission was based on typical patient-level risk factors. Specifically, older patients and greater levels of preoperative chronic comorbidities were important factors associated with early ICU admission among these surgical procedures. In the case of some other procedures, namely open AAA repair, open lung resection and neurosurgery, the prevailing practice at hospitals appeared to be almost automatic early admission to ICU, with less influence from patients' preoperative health status or local ICU capacity. High ICU admission rates seen among these surgeries may partially be due to the traditional perception of these procedures being considered more complex (e.g., higher blood loss, greater associated cardiovascular stress) and concerns regarding the development of early postoperative complications. However, there may be other procedures that are high risk. Increasing evidence demonstrates that surgeries typically associated with lower ICU admission rates, such as colorectal or upper gastrointestinal procedures, are more complex than previously realized. Patients undergoing these procedures are at risk of significant postoperative morbidity (7-17%) and mortality (3.8-13%).[6,8,17]

Hospital-specific ICU bed capacity had a varied relationship with early ICU admission across all procedures. For several surgeries (i.e., upper gastrointestinal, nephrectomy and peripheral arterial disease), the odds of early ICU admission increased with rising percentage of ICU beds. For other procedures, such as lung resection, lower gastrointestinal, neurosurgery and spine surgery, there was a bell-shaped relationship where the odds of early ICU admission increased as ICU bed capacity rose to 10-14%, after which the odds of ICU admission decreased with further increases in ICU bed capacity. ICU bed capacity was assessed as the proportion of ICU beds out of total hospital beds rather than the absolute number of beds given hospitals vary in size across the province.

There are many potential underlying reasons for the variable nature of this association, especially since the relationship of early ICU admission and ICU capacity in surgical services is likely to be highly complex and influenced by local practice policies. Several inter-weaving local factors may be involved and will vary depending on local surgical volumes, surgical expertise conducting complex procedures, ICU bed availability, ward level staffing, and ability to manage complex patients. ICU admission requires both an ICU bed to become available, and sufficient number of ICU-trained nursing staff to care for additional patients. Aside the physical presence of ICU beds in a hospital, the availability of ICU beds is also influenced by demands for these same beds by other specialized elective and emergency services such as trauma, cardiac surgery, organ transplantation and general medicine. Many of these services manage patients in critical care settings, which would lead to an overall decrease in the availability of ICU beds for elective non-cardiac surgical patients. Other important explanations for some surgical patients being less likely to be postoperatively admitted to ICU at hospitals with higher ICU capacity include these hospitals (i) being capable of managing patients for a longer period of time in the postoperative recovery unit, (ii) having lower thresholds for discharging surgical stable patients to a general ward immediately after surgery, and (iii) having the ability to remotely monitor patients in the ward using telemetry systems.

In general, various surgical services within an individual hospital had different patterns of early postoperative ICU admission. However, there was some correlation among services undertaking a similar umbrella of procedures (e.g., general lower and upper gastrointestinal surgery; orthopedic spine, joint replacement and femur surgeries; peripheral arterial disease and EVAR vascular surgery), which are likely to be performed by the same surgical team with similar practice culture, care pathways and levels of access to postoperative ICU. The varied ICU admission rates between surgical procedures is undoubtedly partially due to the diversity in surgical complexity and case mix, but differences in specialty training, cultural opinions and intrinsic practice norms regarding the role of surgical ICU in postoperative care is also likely to play a role. These findings also indicate that evaluation of postoperative ICU utilization should be performed separately for individual surgical procedures, rather than placing all procedures together into a single study group.[21,22,33]

In the absence of clear guidelines on the types of patients and procedures that should have an early postoperative ICU admission, these data indicate that ICU admission is driven largely by individual hospitals' and surgical services' practice patterns. Although there are limited data in the surgical ICU literature, the large between-hospital variation in ICU admission practice that was observed in this thesis is consistent with findings observed for ICU admissions for medical diagnoses.[56,57 58] A study by Admon et al. revealed that the individual hospital accounted for 17.6% (MOR 2.3) of the variation in ICU admissions for 5 common medical diagnoses (i.e., pneumonia, heart failure, myocardial infarct, stroke, chronic obstructive pulmonary disease) and 1 surgical diagnosis (hip arthroplasty) at 1,120 US hospitals.[56] Another study that included 15,949 patients with diabetic ketoacidosis across 159 US hospitals demonstrated that 21.3% of variability in ICU admission was driven by the individual hospital.[57] Several organizational and cultural factors are likely to underpin this behaviour. Beyond surgical complexity, local practice protocols, and the experience or training of surgical staff will inform decisions of where patients should be optimally managed post-surgery. Institutions and individual surgical services will be influenced by several local factors when deciding where different groups of postoperative surgical patients should be managed with the highest quality care. These factors may include availability of general ward medical staff, hospital critical care response team, and experienced nursing staff on surgical wards. These factors are highly likely to be relevant in ICU triage decisions, particularly in smaller rural hospitals that conduct lower volumes of complex cases and have fewer experienced staff to support the postoperative care of these patients in wards. Thus, for some smaller institutions, safe and optimal patient management may be in the ICU despite the higher costs of care. Varied ICU utilization may also be influenced by concerns surrounding medico-legal concerns and financial reimbursement of surgical providers who have access to postoperative ICU areas. Given the lack of quantitative Ontario data on ward level staffing ratios and capabilities of managing complex postoperative patients, I was unable to make any inference on the quality of surgical ward care on early ICU admission rates.

7. 1 What are the implications of these findings and future opportunities?

Critical care utilization in Ontario appears to be greater than many other western countries (9.6% vs. 5%) with similar crude ICU mortality rates (2.4% vs. 2%) in all patients admitted to ICU after surgery.[21] This poses important questions for the delivery of surgical critical care and individual hospitals in Ontario. For example, does postoperative critical care improve patient outcomes, and what local factors are driving ICU admission? Additionally, how does elective surgical utilization impact on ICU bed occupancy rates and the overall availability of ICU beds for other non-surgical services?

Whether surgical ICU is under- or over-utilized in Ontario now requires further close study. Which patients and or surgical procedures would most benefit from routine ICU care is an important question for both patients and the healthcare system. Currently, whether higher ICU utilization translates into improved survival remains debatable. A single surgical-specific study conducted in the US has shown no mortality advantage in hospitals with higher usage of ICU in adult patients undergoing select complex surgeries.[22] The ISOS group examined the effect of postoperative ICU admission on mortality after grouping a variety of cardiac and non-cardiac surgical procedures at the hospital level and showed no benefit of ICU admission.[33] Several medical ICU utilization studies conducted in US hospitals have shown varied effects on patient outcomes.[59,60] These findings now warrant further research within the context of the publicly-funded Canadian healthcare system, which has a lower ICU capacity, different admission patterns, and different financial reimbursement structure compared to the US.

Which components of the perioperative care pathway for surgical patients, either in the ICU or general ward, are the most important for improving outcomes remains unknown. Thus, while ICUs do offer the capacity for close observation of patients, rapid response and intervention for new medical issues, and individualized tailored clinical management, whether these advanced capabilities translate into better patient outcomes requires further investigation. Overly aggressive use of postoperative ICU admission has downsides. For example, routine ICU admission places patients at higher risk of nosocomial sepsis, and is associated with three times the healthcare cost of a standard ward bed ($3,592 vs. $1,135).[3] Thus, understanding the impact of ICU admission on patient outcomes is imperative, especially in light of the current healthcare funding climate. Ontario, like many healthcare jurisdictions, is moving towards quality-based bundled payments for surgical care.[61] This aims to reduce cost and practice variation, while promoting best practice in healthcare. To align healthcare funding with the best patient management, there is a need to understand the place of post-surgical ICU care for different patient and surgical groups.

Thus, assessment of the impact of variation in early ICU admission on patient mortality will be the next stage for my program of research. This assessment can be performed using regression modelling or other advanced methodologies such as propensity score analysis or instrumental variable analysis. In the interim, the findings from my thesis can be used to review local practices surrounding ICU admission decision-making and organizational structures to promote efficient bed use. Institutions and surgical services should review the medical, surgical and organizational factors associated with patients being admitted to ICU after surgery. Important organizational factors that should be discussed include the overall structure of general surgical wards (including bed numbers), optimal numbers and experience of nursing staff, physician availability, and general resources (e.g., monitoring, critical care response teams). These data also allow Ontario hospitals to benchmark where they sit on the curve of ICU utilization after various surgical procedures. Such benchmarking is informative since nearly 50% of all Canadian ICU admissions are related to surgery (cardiac and non-cardiac),[3] and the increase in critical care use in Canada has outpaced the increase in hospital admissions. Over the period 2007/8 to 2013/4, ICU admissions have risen by 12%, as compared to a 7% rise in hospital admissions during the same time frame.[3] This increase has occurred within the context of most ICU facilities situated in large and teaching hospitals in Ontario are running at high occupancy rates (90%) and frequently exceed capacity thresholds.[3] By comparison, the optimal ICU occupancy rate, while not clearly defined, is suggested to be approximately 70-80%.[62,63] Occupancy rates beyond this threshold are associated with challenges in admitting patients quickly to the ICU leading to adverse patient outcomes.[64,65] These detrimental consequences include cancellation of elective surgical procedures, transfer of patients to other acute facilities, premature discharge of patients from the ICU, and delayed access by urgent patients to the ICU.[66,67]

Importantly, not all postoperative patients who are currently admitted to the ICU may *need* to be admitted. Approximately 49% need invasive ventilation, 29% require cardiovascular support and 5% renal replacement therapy.[68] Certainly, surgical patients who require ICU therapies that cannot be administered on a general ward setting will always need postoperative care in an ICU setting. However, not all surgical patients need the advanced care options of ICU and a more considered approach on which patients truly require postoperative ICU care will improve the availability of ICU beds and potentially lower costs of surgical care. For example, lower risk patients who require monitoring, good pain control, and other clinical care (e.g., management of hypothermia) are likely to do well on an adequately resourced surgical ward. Further work is required to better understand postoperative flow care pathways, ICU admission policies, ward or ICU staffing structures, and resource availability in Ontario. This is likely to improve our understanding of the underlying causes of variation elicited in this thesis

7. 2 Study strengths

This study has several important strengths including a large population-based sample, well-validated data, and accurate ascertainment of the timing of both surgery and ICU admission. This study also employed advanced regression modelling that accounted for hospital level clustering and adjusted for many important covariates evaluating the variation and factors associated with early ICU utilization using. This methodology can be applied Canada wide. As indicated previously, my thesis also forms the basis of further outcomes research and will help start a debate regarding local surgical ICU utilization.

7.3 Study limitations

This study also has limitations. First, administrative data are unable to distinguish between organized planned early ICU admission versus an unplanned early ICU admission because of an acute intraoperative event. Nonetheless, unexpected major intraoperative events are generally uncommon; hence unexpected admissions likely represent only a small proportion of the overall study cohort. Second, incomplete risk adjustment with residual unmeasured confounding may still be present. Population-level data does not capture or accurately measure certain characteristics that may be relevant to ICU admission. Examples of such information include intraoperative blood loss, as well as physiological and hemodynamic information. Third, I was unable to quantify the potential impact of other important hospital-level characteristics such as resources and staffing at the level of the ward or ICU given the absence of this information in available datasets. This limitation is important as several previous studies have shown that higher numbers and experience of nursing staff are associated with reduced patient mortality and postoperative complications.[31,69,70] Nursing numbers and experience are also likely to influence where patients are managed after surgical procedures, especially in smaller hospitals.

8. CONCLUSION

This thesis focused on understanding early ICU utilization and hospital variation among various major non-cardiac surgical procedures in Ontario. I have demonstrated higher rates of admission in comparison with Europe with similar ICU mortality rates. There is wide variation in practice between different surgical groups within Ontario that appears to be strongly determined by the individual hospital. It is only within some select surgeries with generally lower rates of ICU admission where consideration of patient-level factors becomes important. These findings merit discussion among physicians, hospital organizational teams and policy-makers to identify the sources of the variation and to question current practice in light of local ICU capacity. Further research is required to understand local factors influencing ICU admission, determine whether ICU care improves postoperative outcomes, and determine the optimal timing and patient selection for ICU care.

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10. APPENDICES

Appendix A Complete abstract

Appendix B Codes and databases used to extract variables from population databases

Appendix C Multilevel logistic regression model outputs for early ICU admission and additional results

APPENDIX A: Complete Abstract

Objective: This thesis assessed the inter-hospital variation in intensive care unit (ICU) utilization and factors associated with ICU admission across Ontario hospitals for adult patients undergoing major non-cardiac surgery.

Methodology: Adult patients undergoing elective non-cardiac surgery in 13 major surgical groups were identified between January 2006 and December 2014 using population-based administrative databases. The primary outcome was early ICU utilization within 24 hours post-surgery. I characterized the extent of inter-hospital variation in the proportion of patients admitted to ICU, and used multilevel logistic regression modelling to examine patient- and hospital-level factors associated with ICU admission for each surgical group. The association of individual hospitals with ICU admission was characterized using the intra-class correlation coefficient (ICC) and median odds ratio (MOR) for all surgical groups.

Results: 541,524 surgical patients across 93 hospitals were included in the study cohort. Early ICU admission occurred in 9.6% of all patients, and varied between 0.9% (hysterectomy) and 90.8% (open abdominal aortic aneurysm repair) for individual surgeries. There was high inter-hospital variation for all individual procedures. The individual hospital where a patient underwent surgery accounted for a large proportion of the variation, with the ICC ranging between 18% for hysterectomy (MOR 2.3) to 75.9% for endovascular aortic aneurysm repair (MOR 21.5).

Conclusion: Ontario hospitals showed wide inter-hospital variation in early ICU admission for various surgical procedures, with a large proportion of this variation attributable to the admitting hospital.

APPENDIX B

Table B1. Surgical procedural and intensive care unit admission codes obtained from the Discharge Abstract Database

VARIABLE	CODES
Vascular Surgery	
Open Abdominal aortic aneurysm repair	CCI 1.KA.76 (all sub-codes) , 1.KA.80.LA, 1.KA.80.LA-XX-A, I.KA.80.LA-XX-K, 1.KA.80.LA.XX-N, 1.KA.80.LA-XX-Q, , 1.KA.87 (should be accompanied with ICD-10 code I71.4 or I71.9 on same admission)
Endovascular Abdominal aortic repair	CCI 1.KA.80.GQ-NR-N
Below Knee Amputation	CCI 1.VQ.93
Above Knee Amputation	CCI 1.VC.93
Peripheral vascular surgery	CCI 1.KG.76, 1.KG.57.LA-X (exclude 1.KG.57.GQ-X), 1.KG.87
General & Hepatobiliary Surgery	
Large Bowel/Rectum surgery	CCI 1.NM.87.LA, 1.NM.87.RN, 1.NM.87.RD, 1.NM.87.RE, 1.NM.87.TF, 1.NM.87.TG, 1.NM.87.WJ (except 1.NM.87.BA), 1.NM.89.RN, 1.NM.89.TF, 1.NM.91.RN, 1.NM.91.RD, 1.NM.91.RE, 1.NM.91.TF, 1.NM.91, TG, 1.NQ.87 (except 1.NQ.87.BA), 1.NQ.89, CCI 1.NM.87.DA, 1.NM.87.DF. 1.NM.87.DE, 1.NM.87.DN, 1.NM.87.DX, 1.NM.87.DY, 1.NM.87.GB, 1.NM.89.DF, 1.NM.89.DX, 1.NM.91.DF, 1.NM.91.DE, 1.NM.91.DN, 1.NM.91.DX, 1.NM.91.DY
Gastrectomy	CCI 1.NF.87.RP, 1.NF.87.RG, 1.NF.87.RJ, 1.NF.87.LA, 1.NF.87.SH, 1.NF.87.RH, 1.NF.87.RK 1.NF.89.LA-XX-F, 1.NF.91 (all sub-codes) 1.NF.89.DA-XX-F, 1.NF.87.DG, 1.NF.87.DH, 1.NF.87.DQ, 1.NF.87.DA, 1.NF.87.GX, 1.NF.87.DJ, 1.NF.87.DL
Esophagectomy	CCI 1.NA.87.LP, 1.NA.87.LB, 1.NA.87.LB-XX-G, 1.NA.87.LB-XX-F, 1.NA.89.LB, 1.NA.89.LB-XX-G, 1.NA.89.LB-XX-F, 1.NA.89.QF, 1.NA.89.QF-XX-G, 1.NA.89.QF-XX-F, 1.NA.90, 1.NA.91.LB, 1.NA.91.LB-XX-G, 1.NA.91.LB-XX-F, 1.NA.91.QF, 1.NA.91.QF-XX-G, 1.NA.91.QF-XX-F CCI 1.NA.87.DB, 1.NA.87.DB-XX-G, 1.NA.87.DB-XX-F, 1.NA.87.EZ, 1.NA.87.FA, 1.NA.87.FA-XX-G, 1.NA.87.FA-XX-F, 1.NA.91.DB, 1.NA.91.DB-XX-G, 1.NA.91.DB-XX-F, 1.NA.91.FA, 1.NA.91.FA-XX-G, 1.NA.91.FA-XX-F

Partial Liver resection + Biliary bypass	CCI 1.OA.87.LA, 1.OA.87.LA-AZ, 1.0E.80.(all sub-codes), 1.OE.76.(all sub-codes), CCI 1.OA.87.DA
Pancreatic surgery + Pancreatico-duodenectomy	CCI 1.OJ.87, 1.OJ.89, 1.OK.87, 1.OK.89, 1.OK.91
Thoracic Surgery	
Open Pneumonectomy + lobectomy	CCI 1.GR.87.NW, 1.GR.87.QB, 1.GR.89.NW, 1.GR.89.QB, 1.GR.91.NW, 1.GR.91.NW-XX-A to 1.GR.91.NW-XX-L (all intervening codes), 1.GT.87.NW, 1.GT.87.QB, 1.GT.89.NW, 1.GT.89.QB, 1.GT.91 (ALL CODES)
VATS lobectomy	CCI 1.GR.87.DA, 1.GR.89.DA, 1.GT.87.DA, 1.GT.89.DA
Major Uro-gynaecology Surgery	
Nephrectomy	CCI 1.PC.87.LA, 1.PC.87.LA-XX-E, 1.PC.87.LA-XX-G, 1.PC.89.LB, 1.PC.89.PF, 1.PC.89.QF, 1.PC.91.LB, 1.PC.89.PF, 1.PC.91.QF, 1.PC.87.DA, 1.PC.89.DA, 1.PC.91.DA
Hysterectomy	CCI 1.RM.89.LA , 1.RM.91.LA, 1.RM.89.AA, 1.RM.89.CA, 1.RM.89.DA, 1.RM.91.AA, 1.RM.91.CA, 1.RM.91.DA
Orthopaedic Surgery	
Total Hip Joint Replacement	CCI 1.VA.53
Femur surgery	CCI 1.VC.74, 1.VC.80, 1.VC.73, 1.VC.87, 1.VC.91
Total Knee replacement	CCI 1.VG.53
Spinal surgery	CCI 1.SC.74, 1.SC.75, 1.SC.80, 1.SC.87, 1.SC.89
Neurosurgery	
Open craniotomy, craniectomy, posterior fossa surgery	CCI 1.AA.52 (EXCEPT 1.AA.52.HA, percutaneous approach), 1.AB.52, 1.AC.87, 1.AJ87, 1.AK87, 1.AN.87
Exposure	
ICU Admission	Special Care Unit (SCU)

Table B2. Patient comorbidities were identified using International Classification of Diseases (ICD) 10 codes in the Discharge Abstract Database unless specified otherwise.

VARIABLE	CODES
Myocardial Infarction	ICD-10 I21.0-I21.9, I22.0-I22.9, I25.2
Coronary artery disease	ICD-10 I20, I21, I22, I23, I24, I25
Congestive heart failure	CHF database: DIAGDATE any point prior to indexed surgical procedure.
Atrial fibrillation	ICD-10 I48
Diabetes Mellitus	ODD database: DIAGDATE any point prior to indexed surgical procedure.
Diabetes without complications	ICD-10 E10.0, E10.1. E10.6, E10.8, E10.9, E11.0, E11.1. E11.6, E11.8, E11.9, E12.0, E12.1, E12.6, E12.8, E12.9, E13.0, E13.1, E13.6, E13.8, E13.9, E14.0, E14.1, E14.6, E14.8, E14.9
Diabetes with chronic complications	ICD-10 E10.2-E10.5, E10.7, E11.2-E11.5, E11.7, E12.2-12.5, E12.7, E13.2-E13.5, E13.7, E14.2-14.5, E14.7
Hypertension	HYPER database: DIAGDATE any point prior to indexed surgical procedure.
Cerebrovascular disease	ICD-10 I60, 161, 163, I64, I65, I66, I67, I68, I69, G45.x, G46.x, H340
Hemiplegia or Paraplegia	ICD-10 codes G04.1; G11.4; G80.1, G80.2, G81, G82, G83.0, G83.4, G83.9
Peripheral vascular Disease	ICD-10 codes I70, I71, I73.1, I73.8, I73.9, I77.1, I79, K55.1, ZZ95.8, Z95.9 K55.8 K55.9
Chronic Renal Insufficiency	ICD-10 codes I12.0, I13, N03.2 - N03.7, N05.2-N05.7, N18; N19; N25.0; Z49.0-Z49.2, Z94.0, Z99.2
Dialysis (pre-surgery)	OHIP G326, G860, G862, G863, G865, G866,G332, G861, G864
Chronic lung disease - Asthma, COPD	ASTHMA database: ADMDATE any point prior to indexed surgical procedure. COPD database: DIAGDATE any point prior to indexed surgical procedure.
Dementia	ICD-10 F00 - F03, F05.1, G30, G31.1
Venous Thromboembolic disease	ICD-10 I80.0, I80.1, I80.2, I80.8, I82.2, I82.8, I82.9
Primary Malignancy	ICD-10 C00.0-26.9, C30-34.99, c37-41.9, C45.0-58, C60-76, C81-85, C88, C90-97
Secondary Malignancy	ICD-10 C77.0-C80.9
Rheumatological disease	ICD-10 M05, M06, M31.5, M32-34, M35.1, M35.3, M360
Liver disease	ICD-10 B18, K70.0 - K70.3, K70.9, K71.3 - K71.5, K71.7, K73, K74, K76.0, K76.2 - K76.4, K76.8, K76.9, Z94.4, I85.0, I85.9,

	I86.4, I98.2, K70.4, K71.1, K72.1,K72.9; K76.5, K76.6, K76.7
Mild Liver Disease	ICD B18.x, K70-K70.3, K70.9, K71.3-K71.5, K71.7, K73.x, K74.x, K76.0, K76.2-K76.4, K76.8, K76.9, Z94.4
Moderate or severe Liver disease	ICD I85.0, I85.9, I86.4, I98.2, K70.4, K71.1, K72.1, K72.9, K76.5, K76.6, K76.7
Peptic Ulcer disease	ICD-10 K25-28
AIDS/HIV	ICD-10 B20.x-B22.x, B24.x
Trauma	ICD-10 S00-S09.9, S10-19.9, S20-29.9, S30-39.9, S40-69.9, S70-79.9, S80-89.9, S90-99.9 T00-T14.9, T15-T19.9

Comorbidities identified up to 3 years prior to the surgical intervention.
CHF Congestive heart failure; COPD Chronic obstructive pulmonary disease; HYPER Hypertension; ODD Ontario diabetes database; OHIP Ontario Health Insurance Plan

APPENDIX C

Table C1. Regression models for all elective surgical groups assessing the outcome of early ICU admission.*

	NEUROSURGERY							OPEN ABDOMINAL AORTIC ANEURYSM						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	0.3607	0.0656	1.4344	1.2614	1.6311	30.28	0.0000	-0.2523	0.1444	0.7770	0.5855	1.0311	3.05	0.0805
_RCS1	-0.0033	0.0005	0.9967	0.9957	0.9977	40.90	0.0000	0.0008	0.0011	1.0008	0.9987	1.0029	0.53	0.4665
Duration Surgery[1]	0.0424	0.0127	1.0434	1.0177	1.0696	11.21	0.0008	0.0202	0.0157	1.0204	0.9895	1.0523	1.66	0.1977
Teaching status	-0.4360	0.4160	0.6466	0.2861	1.4613	1.10	0.2946	0.3922	0.5008	1.4802	0.5547	3.9498	0.61	0.4336
Surgical Volume	0.0007	0.0007	1.0007	0.9993	1.0022	0.98	0.3211	-0.0058	0.0011	0.9942	0.9921	0.9964	28.29	0.0000
Age[2]	-0.0468	0.0298	0.9543	0.9002	1.0117	2.46	0.1166	0.1162	0.0468	1.1233	1.0249	1.2311	6.18	0.0129
Male	-0.0223	0.0771	0.9779	0.8408	1.1374	0.08	0.7719	-0.0527	0.0709	0.9486	0.8256	1.0900	0.55	0.4570
Charlson ≥ 2	-0.0800	0.0826	0.9231	0.7851	1.0854	0.94	0.3330	-0.0841	0.1693	0.9194	0.6598	1.2811	0.25	0.6195
Rural	0.0506	0.1133	1.0519	0.8425	1.3134	0.20	0.6550	0.1141	0.1038	1.1208	0.9145	1.3737	1.21	0.2717
CAD	-0.0820	0.2993	0.9213	0.5125	1.6562	0.08	0.7842	-0.0921	0.1059	0.9120	0.7411	1.1224	0.76	0.3845
Myocardial infarct	0.4555	0.5125	1.5770	0.5775	4.3061	0.79	0.3741	0.1932	0.2068	1.2132	0.8088	1.8196	0.87	0.3502
Renal Disease	-0.2808	0.4530	0.7552	0.3108	1.8349	0.38	0.5353	0.0574	0.4148	1.0591	0.4698	2.3878	0.02	0.8899
COPD	0.1634	0.0800	1.1775	1.0067	1.3773	4.18	0.0410	0.0337	0.0887	1.0343	0.8693	1.2306	0.14	0.7035
Asthma	0.0601	0.0833	1.0619	0.9020	1.2502	0.52	0.4708	0.0307	0.1514	1.0312	0.7664	1.3874	0.04	0.8393
Primary cancer	0.1551	0.1054	1.1678	0.9499	1.4357	2.17	0.1410	0.1379	0.3134	1.1479	0.6211	2.1214	0.19	0.6598
Secondary cancer	-0.0038	0.1293	0.9962	0.7731	1.2837	0.00	0.9767	-0.3554	0.3930	0.7009	0.3244	1.5142	0.82	0.3659
Diabetes	-0.0894	0.0966	0.9145	0.7568	1.1050	0.86	0.3546	-0.0860	0.0921	0.9176	0.7661	1.0991	0.87	0.3502
Liver Disease	0.1309	0.4691	1.1399	0.4545	2.8589	0.08	0.7802	-0.8709	0.2925	0.4186	0.2359	0.7426	8.87	0.0029
Hypertension	-0.0043	0.0687	0.9957	0.8703	1.1391	0.00	0.9496	-0.0278	0.0744	0.9726	0.8406	1.1254	0.14	0.7091
Stroke	-0.2049	0.1285	0.8148	0.6333	1.0482	2.54	0.1110	0.0702	0.1644	1.0728	0.7772	1.4807	0.18	0.6692
Atrial fibrillation	-0.1992	0.1511	0.8194	0.6094	1.1018	1.74	0.1874	0.0553	0.1859	1.0568	0.7341	1.5214	0.09	0.7662

**Logistic regression models estimated using a general estimating equation*

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	ENDOVASCULAR AORTIC ANEURYSM REPAIR							UPPER GASTROINTESTINAL SURGERY						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	0.0030	0.2228	1.0030	0.6482	1.5521	0.00	0.9892	0.0061	0.1310	1.0061	0.7782	1.3007	0.00	0.9631
_RCS1	-0.0004	0.0012	0.9996	0.9971	1.0020	0.12	0.7324	0.0014	0.0021	1.0014	0.9973	1.0055	0.45	0.5041
Duration Surgery[1]	0.0763	0.0232	1.0793	1.0313	1.1295	10.80	0.0010	0.0563	0.0136	1.0580	1.0302	1.0864	17.28	0.0000
Teaching status	0.5206	1.4186	1.6831	0.1044	27.1434	0.13	0.7136	-1.4544	0.4737	0.2335	0.0923	0.5910	9.43	0.0021
Surgical Volume	-0.0021	0.0012	0.9979	0.9956	1.0001	3.42	0.0646	0.0000	0.0002	1.0000	0.9995	1.0004	0.01	0.9372
Age[2]	-0.0061	0.0397	0.9940	0.9195	1.0745	0.02	0.8787	0.1169	0.0415	1.1240	1.0362	1.2191	7.95	0.0048
Male	0.0988	0.0933	1.1039	0.9193	1.3255	1.12	0.2897	-0.0057	0.0479	0.9943	0.9051	1.0922	0.01	0.9048
Charlson ≥ 2	0.0379	0.0984	1.0386	0.8565	1.2594	0.15	0.7000	0.0399	0.0835	1.0407	0.8836	1.2257	0.23	0.6327
Rural	-0.7917	0.2589	0.4531	0.2728	0.7526	9.35	0.0022	-0.2488	0.1635	0.7797	0.5660	1.0743	2.32	0.1281
CAD	0.3015	0.1512	1.3518	1.0052	1.8181	3.98	0.0461	0.0912	0.1234	1.0954	0.8602	1.3951	0.55	0.4600
Myocardial infarct	-0.0743	0.1773	0.9284	0.6558	1.3142	0.18	0.6751	0.0782	0.1509	1.0813	0.8045	1.4535	0.27	0.6043
Renal Disease	-0.1881	0.1137	0.8286	0.6630	1.0355	2.73	0.0982	0.4910	0.2271	1.6339	1.0469	2.5501	4.67	0.0306
COPD	0.0076	0.0653	1.0077	0.8867	1.1452	0.01	0.9067	0.1396	0.0442	1.1498	1.0543	1.2538	9.96	0.0016
Asthma	0.0991	0.0958	1.1041	0.9151	1.3322	1.07	0.3011	-0.0025	0.0681	0.9975	0.8730	1.1399	0.00	0.9710
Primary cancer	0.1726	0.1176	1.1884	0.9438	1.4965	2.15	0.1421	0.4856	0.1141	1.6251	1.2993	2.0326	18.10	0.0000
Secondary cancer	0.7478	0.2054	2.1124	1.4122	3.1598	13.25	0.0003	-0.0414	0.0495	0.9594	0.8708	1.0571	0.70	0.4025
Diabetes	0.1133	0.0430	1.1200	1.0294	1.2186	6.93	0.0085	-0.0476	0.0494	0.9535	0.8655	1.0505	0.93	0.3355
Liver Disease	-0.1268	0.3337	0.8809	0.4580	1.6942	0.14	0.7039	0.3975	0.2527	1.4881	0.9068	2.4421	2.47	0.1157
Hypertension	0.1661	0.0836	1.1807	1.0023	1.3909	3.95	0.0469	0.1259	0.0439	1.1342	1.0407	1.2361	8.23	0.0041
Stroke	-0.0123	0.2371	0.9878	0.6207	1.5720	0.00	0.9586	-0.0575	0.1878	0.9441	0.6534	1.3642	0.09	0.7595
Atrial fibrillation	0.0356	0.1078	1.0362	0.8389	1.2800	0.11	0.7414	0.2878	0.0791	1.3335	1.1419	1.5572	13.23	0.0003

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	LOWER GASTROINTESTINAL SURGERY							NEPHRECTOMY						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	0.1235	0.0840	1.1315	0.9598	1.3339	2.16	0.1412	0.1491	0.1048	1.1608	0.9453	1.4253	2.03	0.1547
_RCS1	-0.0032	0.0019	0.9968	0.9931	1.0005	2.87	0.0903	-0.0019	0.0026	0.9981	0.9931	1.0031	0.57	0.4510
Duration Surgery[1]	0.0571	0.0079	1.0587	1.0424	1.0753	51.76	0.0000	0.0441	0.0124	1.0451	1.0200	1.0707	12.70	0.0004
Teaching status	-0.5057	0.3700	0.6031	0.2921	1.2455	1.87	0.1717	-1.1171	0.5865	0.3272	0.1037	1.0329	3.63	0.0568
Surgical Volume	-0.0008	0.0003	0.9992	0.9986	0.9999	5.64	0.0176	-0.0003	0.0007	0.9997	0.9984	1.0011	0.14	0.7051
Age[2]	0.3265	0.0259	1.3861	1.3174	1.4583	158.52	0.0000	0.2172	0.0244	1.2425	1.1845	1.3034	79.28	0.0000
Male	-0.0230	0.0298	0.9772	0.9219	1.0359	0.60	0.4393	0.0117	0.0595	1.0117	0.9004	1.1368	0.04	0.8443
Charlson ≥ 2	0.3258	0.0640	1.3851	1.2218	1.5702	25.92	0.0000	0.4210	0.1458	1.5234	1.1448	2.0273	8.34	0.0039
Rural	0.4362	0.1229	1.5468	1.2156	1.9683	12.59	0.0004	0.0471	0.1731	1.0483	0.7466	1.4718	0.07	0.7854
CAD	0.5949	0.0744	1.8128	1.5669	2.0972	64.00	0.0000	0.4971	0.1048	1.6439	1.3387	2.0187	22.50	0.0000
Myocardial infarct	0.1569	0.0985	1.1699	0.9645	1.4189	2.54	0.1112	-0.0246	0.1843	0.9757	0.6798	1.4003	0.02	0.8938
Renal Disease	0.4809	0.1142	1.6175	1.2933	2.0231	17.75	0.0000	0.4625	0.1755	1.5880	1.1259	2.2398	6.95	0.0084
COPD	0.4027	0.0519	1.4958	1.3513	1.6559	60.28	0.0000	0.4214	0.0813	1.5240	1.2995	1.7873	26.86	0.0000
Asthma	0.0425	0.0415	1.0434	0.9619	1.1319	1.05	0.3059	0.2293	0.0770	1.2578	1.0815	1.4627	8.87	0.0029
Primary cancer	0.0968	0.0618	1.1017	0.9760	1.2435	2.46	0.1170	0.0184	0.1463	1.0185	0.7647	1.3567	0.02	0.9001
Secondary cancer	-0.2049	0.0823	0.8147	0.6933	0.9573	6.20	0.0128	0.4186	0.1480	1.5198	1.1371	2.0313	8.00	0.0047
Diabetes	0.1334	0.0416	1.1427	1.0532	1.2397	10.28	0.0013	0.2446	0.0635	1.2772	1.1276	1.4465	14.83	0.0001
Liver Disease	0.3690	0.1674	1.4463	1.0416	2.0081	4.86	0.0276	0.0526	0.2865	1.0540	0.6011	1.8482	0.03	0.8543
Hypertension	0.1771	0.0615	1.1937	1.0581	1.3467	8.28	0.0040	0.2007	0.0670	1.2222	1.0717	1.3939	8.96	0.0028
Stroke	0.2933	0.0909	1.3409	1.1220	1.6025	10.41	0.0013	0.0477	0.1971	1.0489	0.7128	1.5433	0.06	0.8086
Atrial fibrillation	0.5181	0.0698	1.6789	1.4643	1.9249	55.13	0.0000	0.5006	0.1153	1.6498	1.3160	2.0682	18.84	0.0000

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	SPINE SURGERY							JOINT REPLACEMENT SURGERY						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	0.3023	0.2801	1.3529	0.7814	2.3424	1.17	0.2804	-0.1221	0.1506	0.8850	0.6588	1.1889	0.66	0.4173
_RCS1	-0.0028	0.0026	0.9972	0.9920	1.0023	1.17	0.2803	0.0027	0.0030	1.0027	0.9968	1.0086	0.82	0.3643
Duration Surgery[1]	0.0642	0.0095	1.0663	1.0466	1.0864	45.66	0.0000	0.0664	0.0102	1.0687	1.0475	1.0902	42.44	0.0000
Teaching status	0.7465	0.5556	2.1097	0.7100	6.2687	1.81	0.1791	-0.0987	0.4672	0.9060	0.3626	2.2637	0.04	0.8326
Surgical Volume	0.0005	0.0002	1.0005	1.0001	1.0009	5.64	0.0176	0.0001	0.0000	1.0001	1.0001	1.0002	11.50	0.0007
Age[2]	-0.0185	0.0990	0.9817	0.8086	1.1919	0.03	0.8520	0.0557	0.0560	1.0573	0.9473	1.1801	0.99	0.3200
Male	0.0300	0.0592	1.0304	0.9176	1.1571	0.26	0.6125	0.2895	0.0414	1.3358	1.2317	1.4486	48.92	0.0000
Charlson ≥ 2	0.5088	0.1037	1.6634	1.3573	2.0384	24.06	0.0000	0.4443	0.0615	1.5594	1.3823	1.7591	52.19	0.0000
Rural	-0.3565	0.0476	0.7001	0.6377	0.7686	55.99	0.0000	0.0733	0.1082	1.0761	0.8705	1.3302	0.46	0.4978
CAD	0.5223	0.1488	1.6859	1.2593	2.2570	12.31	0.0004	0.7856	0.1442	2.1938	1.6536	2.9104	29.67	0.0000
Myocardial infarct	0.0518	0.2043	1.0532	0.7058	1.5717	0.06	0.7996	0.0895	0.1231	1.0937	0.8593	1.3920	0.53	0.4668
Renal Disease	0.1779	0.1807	1.1947	0.8384	1.7025	0.97	0.3248	0.3950	0.1285	1.4843	1.1539	1.9094	9.45	0.0021
COPD	0.1637	0.0898	1.1779	0.9878	1.4045	3.32	0.0683	0.4785	0.0553	1.6137	1.4478	1.7985	74.79	0.0000
Asthma	0.1093	0.0672	1.1155	0.9777	1.2726	2.64	0.1041	0.2385	0.0342	1.2694	1.1872	1.3573	48.76	0.0000
Primary cancer	0.2309	0.1218	1.2597	0.9921	1.5994	3.59	0.0581	-0.2913	0.1039	0.7473	0.6097	0.9161	7.86	0.0050
Secondary cancer	-0.1112	0.2083	0.8948	0.5948	1.3459	0.28	0.5935	0.1199	0.1947	1.1274	0.7697	1.6513	0.38	0.5381
Diabetes	0.1184	0.0709	1.1257	0.9797	1.2935	2.79	0.0947	0.4009	0.0276	1.4932	1.4144	1.5763	210.36	0.0000
Liver Disease	0.1973	0.2012	1.2182	0.8211	1.8071	0.96	0.3268	0.4695	0.1770	1.5992	1.1305	2.2624	7.04	0.0080
Hypertension	0.1193	0.0589	1.1267	1.0040	1.2645	4.11	0.0427	0.5121	0.0695	1.6688	1.4563	1.9123	54.29	0.0000
Stroke	0.0632	0.2268	1.0653	0.6830	1.6616	0.08	0.7804	0.2208	0.0986	1.2471	1.0279	1.5130	5.01	0.0251
Atrial fibrillation	0.6646	0.1609	1.9437	1.4179	2.6646	17.05	0.0000	0.7638	0.0909	2.1463	1.7962	2.5647	70.65	0.0000

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	FEMUR SURGERY							PERIPHERAL ARTERIAL DISEASE						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	-0.2981	0.3527	0.7422	0.3718	1.4817	0.71	0.3980	0.0899	0.1614	1.0941	0.7973	1.5013	0.31	0.5776
_RCS1	0.0128	0.0119	1.0129	0.9895	1.0369	1.16	0.2821	-0.0006	0.0019	0.9994	0.9958	1.0031	0.09	0.7689
Duration Surgery[1]	0.0593	0.0166	1.0611	1.0271	1.0962	12.76	0.0004	0.0722	0.0138	1.0749	1.0461	1.1045	27.19	0.0000
Teaching status	1.4375	0.8958	4.2102	0.7274	24.3679	2.58	0.1086	-1.3665	0.9773	0.2550	0.0376	1.7313	1.96	0.1620
Surgical Volume	0.0032	0.0033	1.0032	0.9967	1.0097	0.92	0.3383	-0.0007	0.0009	0.9993	0.9976	1.0010	0.67	0.4147
Age[2]	0.1213	0.0412	1.1289	1.0414	1.2238	8.67	0.0032	0.0271	0.0237	1.0274	0.9808	1.0763	1.30	0.2536
Male	0.1439	0.2761	1.1547	0.6722	1.9836	0.27	0.6023	-0.0197	0.0679	0.9805	0.8583	1.1201	0.08	0.7718
Charlson ≥ 2	0.7873	0.2377	2.1974	1.3792	3.5012	10.97	0.0009	-0.1859	0.0887	0.8303	0.6978	0.9881	4.39	0.0362
Rural	-0.3630	0.4018	0.6956	0.3165	1.5289	0.82	0.3663	-0.2055	0.1987	0.8142	0.5516	1.2018	1.07	0.3009
CAD	0.5352	0.2508	1.7078	1.0446	2.7919	4.55	0.0328	-0.0006	0.1149	0.9994	0.7979	1.2519	0.00	0.9962
Myocardial infarct	1.5405	0.6078	4.6668	1.4178	15.3605	6.42	0.0113	0.2804	0.1375	1.3236	1.0109	1.7332	4.16	0.0415
Renal Disease	0.7158	0.7787	2.0457	0.4447	9.4113	0.84	0.3580	0.1346	0.1395	1.1441	0.8703	1.5039	0.93	0.3348
COPD	0.5772	0.4108	1.7810	0.7962	3.9838	1.97	0.1600	0.2320	0.0969	1.2611	1.0430	1.5247	5.73	0.0166
Asthma	0.4668	0.2599	1.5948	0.9582	2.6544	3.22	0.0725	-0.1385	0.1032	0.8707	0.7113	1.0658	1.80	0.1796
Primary cancer	-1.0445	0.2097	0.3519	0.2333	0.5308	24.81	0.0000	-0.0093	0.1777	0.9907	0.6994	1.4034	0.00	0.9582
Secondary cancer	-0.1912	0.2888	0.8259	0.4690	1.4546	0.44	0.5078	0.0823	0.3559	1.0857	0.5405	2.1810	0.05	0.8172
Diabetes	0.2561	0.1461	1.2918	0.9702	1.7201	3.07	0.0796	0.0335	0.0620	1.0341	0.9158	1.1676	0.29	0.5885
Liver Disease	0.1176	1.0431	1.1248	0.1456	8.6882	0.01	0.9102	0.0344	0.2070	1.0350	0.6898	1.5529	0.03	0.8682
Hypertension	0.5336	0.3451	1.7050	0.8669	3.3533	2.39	0.1221	0.1133	0.0838	1.1200	0.9503	1.3200	1.83	0.1765
Stroke	-0.3406	0.8464	0.7113	0.1354	3.7371	0.16	0.6874	0.0509	0.1401	1.0523	0.7996	1.3848	0.13	0.7162
Atrial fibrillation	1.1650	0.6922	3.2059	0.8255	12.4502	2.83	0.0924	0.2048	0.0810	1.2273	1.0471	1.4386	6.39	0.0115

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	OPEN LUNG RESECTION							VATS LUNG RESECTION						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	0.3325	0.1913	1.3945	0.9584	2.0289	3.02	0.0822	1.0515	0.2742	2.8621	1.6723	4.8983	14.71	0.0001
_RCS1	-0.0167	0.0060	0.9835	0.9720	0.9951	7.70	0.0055	-0.0403	0.0085	0.9605	0.9446	0.9767	22.34	0.0000
Duration Surgery[1]	0.0189	0.0155	1.0191	0.9887	1.0504	1.49	0.2218	0.0448	0.0136	1.0458	1.0184	1.0740	10.91	0.0010
Teaching status	-0.3015	0.4405	0.7397	0.3120	1.7537	0.47	0.4936	0.2029	0.5377	1.2249	0.4270	3.5137	0.14	0.7059
Surgical Volume	-0.0010	0.0004	0.9990	0.9982	0.9998	5.58	0.0181	-0.0010	0.0007	0.9990	0.9977	1.0003	2.47	0.1157
Age[2]	0.0957	0.0311	1.1005	1.0353	1.1697	9.46	0.0021	0.1668	0.0388	1.1815	1.0949	1.2750	18.44	0.0000
Male	-0.0084	0.0483	0.9917	0.9021	1.0902	0.03	0.8626	-0.0923	0.0584	0.9119	0.8132	1.0225	2.49	0.1144
Charlson ≥ 2	-0.0324	0.1003	0.9681	0.7954	1.1784	0.10	0.7467	0.2354	0.0723	1.2655	1.0982	1.4581	10.60	0.0011
Rural	0.2253	0.1737	1.2527	0.8912	1.7609	1.68	0.1947	-0.0140	0.1976	0.9861	0.6694	1.4526	0.01	0.9435
CAD	0.2011	0.1267	1.2227	0.9539	1.5673	2.52	0.1124	0.0402	0.1138	1.0410	0.8329	1.3012	0.12	0.7240
Myocardial infarct	0.1030	0.1583	1.1085	0.8128	1.5117	0.42	0.5152	0.3165	0.2224	1.3724	0.8875	2.1221	2.03	0.1546
Renal Disease	0.2552	0.2496	1.2907	0.7914	2.1049	1.05	0.3066	0.0506	0.1591	1.0519	0.7701	1.4368	0.10	0.7504
COPD	0.1986	0.0628	1.2197	1.0783	1.3796	9.99	0.0016	0.1104	0.1296	1.1167	0.8662	1.4396	0.73	0.3944
Asthma	0.0022	0.0480	1.0022	0.9123	1.1011	0.00	0.9628	-0.0555	0.0577	0.9460	0.8448	1.0593	0.92	0.3363
Primary cancer	-0.0871	0.0736	0.9166	0.7934	1.0589	1.40	0.2371	-0.1217	0.0692	0.8854	0.7731	1.0140	3.09	0.0787
Secondary cancer	-0.0856	0.0957	0.9179	0.7610	1.1073	0.80	0.3708	-0.0634	0.0645	0.9386	0.8271	1.0652	0.96	0.3261
Diabetes	0.2369	0.0722	1.2673	1.1001	1.4599	10.77	0.0010	0.1143	0.0527	1.1210	1.0110	1.2431	4.70	0.0302
Liver Disease	0.3464	0.2400	1.4140	0.8833	2.2633	2.08	0.1490	0.0925	0.2041	1.0969	0.7352	1.6364	0.21	0.6505
Hypertension	0.0606	0.0515	1.0625	0.9605	1.1752	1.39	0.2389	-0.0691	0.0555	0.9332	0.8370	1.0405	1.55	0.2132
Stroke	-0.0383	0.1421	0.9624	0.7284	1.2716	0.07	0.7875	0.0657	0.1840	1.0679	0.7446	1.5315	0.13	0.7210
Atrial fibrillation	0.2912	0.1285	1.3380	1.0401	1.7212	5.14	0.0234	-0.0686	0.1339	0.9337	0.7183	1.2138	0.26	0.6083

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years

	HYSTERECTOMY						
Label	**Estimate**	**StdErr**	**OR**	**Lower CL**	**Upper CL**	**ChiSq**	**P-value**
ICU bed proportion	-0.0520	0.1078	0.9493	0.7685	1.1726	0.23	0.6294
_RCS1	0.0010	0.0025	1.0010	0.9960	1.0059	0.15	0.7034
Duration Surgery[1]	0.0748	0.0059	1.0777	1.0653	1.0902	160.82	0.0000
Teaching status	0.5229	0.5176	1.6870	0.6116	4.6529	1.02	0.3124
Surgical Volume	-0.0003	0.0002	0.9997	0.9994	1.0001	2.08	0.1494
Age[2]	0.1562	0.0381	1.1690	1.0850	1.2596	16.82	0.0000
Charlson ≥ 2	1.0328	0.1305	2.8089	2.1749	3.6277	62.62	0.0000
Rural	0.0640	0.1151	1.0660	0.8507	1.3359	0.31	0.5785
CAD	0.9487	0.2276	2.5825	1.6531	4.0344	17.37	0.0000
Myocardial infarct	-0.0117	0.2916	0.9884	0.5581	1.7503	0.00	0.9680
Renal Disease	0.5408	0.2752	1.7173	1.0014	2.9452	3.86	0.0494
COPD	0.5908	0.0973	1.8054	1.4919	2.1847	36.86	0.0000
Asthma	0.2301	0.0854	1.2587	1.0648	1.4879	7.26	0.0070
Primary cancer	-0.0924	0.1268	0.9117	0.7112	1.1689	0.53	0.4659
Secondary cancer	-0.1883	0.1397	0.8284	0.6300	1.0893	1.82	0.1778
Diabetes	0.4095	0.0756	1.5060	1.2985	1.7467	29.30	0.0000
Liver Disease	0.4881	0.3501	1.6293	0.8203	3.2361	1.94	0.1633
Hypertension	0.5120	0.0714	1.6686	1.4506	1.9193	51.38	0.0000
Stroke	-0.2745	0.2409	0.7600	0.4739	1.2186	1.30	0.2545
Atrial fibrillation	1.0085	0.1233	2.7414	2.1531	3.4905	66.95	0.0000

_RCS1 Restricted cubic spline; CAD Coronary artery disease; COPD Chronic obstructive pulmonary disease; StdErr Standard error; OR Odds ratio; CL Confidence limit

[1]Duration of surgery for every 10 min; [2]Age for every 10 years