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Intensive care utilization following major noncardiac surgical procedures in Ontario, Canada: a population-based study

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Abstract

Purpose: Patients are sometimes admitted to intensive care units (ICU) after elective noncardiac surgery for advanced monitoring and treatments not available on a general postsurgical ward. However, patterns of ICU utilization are poorly understood. Our aims were to assess the incidence and determinants of ICU utilization after elective noncardiac surgical procedures.

Methods: Population-based cohort study included adult patients who underwent 13 types of major elective noncardiac surgical procedures between 2006 and 2014 in Ontario, Canada. Primary outcome was early admission to ICU within 24 h after surgery. A prespecified analysis using multilevel logistic regression modeling separately examined patient- and hospital-level factors associated with early ICU admission within distinct groups of surgical procedures.

Results: Early ICU admission occurred in 9.6% of the included 541,524 patients. Patients admitted early to ICU showed higher median age (68 vs. 65 years), burden of prehospital comorbidities (Charlson comorbidity index score ≥ 2, 33.1 vs. 10.4%), 30-day mortality rates (2.4 vs. 0.3%), and longer median postoperative hospital stays (6 vs. 4 days) than patients admitted to a ward. There was wide variation in proportions of patients admitted early to ICU across different surgery types (0.9% for hysterectomy to 90.8% for open abdominal aortic aneurysm repair) with generally low 30-day mortality across procedures (0.1–2.8%). Within individual procedures, there was wide interhospital variation in the range of early ICU admission rates (hysterectomy 0.07–14.4%, lower gastrointestinal resection 1.3–95%, endovascular aortic aneurysm 1.3–95.2%). The individual hospital where surgery was performed accounted for a large proportion of the variation in early ICU admission rates, with the median odds ratio ranging from 2.3 for hysterectomy to 21.5 for endovascular aortic aneurysm.

Conclusions: There is a wide variation in early ICU admission across and within surgical procedures. The individual hospital accounts for a large proportion of this variation. Further research is required to identify the basis for this variation and to develop better methods for allocating ICU resources for postoperative management of surgical patients.

Keywords: Critical care, Surgery, Epidemiology, Health services research

Introduction

Over 300 million surgical procedures are performed worldwide each year [1]. Many patients who undergo complex elective noncardiac surgical procedures are admitted to intensive care units (ICU) postoperatively for close continuous monitoring and end-organ supportive therapies that cannot be delivered on a general ward. Postoperative care in ICU environments also facilitates more tailored patient care and rapid response to acute postoperative problems. Surgical patients managed in ICUs postoperatively are usually older with greater

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levels of prehospital comorbidities and thus demonstrate higher risk-adjusted mortality in comparison to patients admitted to a non-critical care environment [2]. These mortality rates are further raised in patients admitted later to ICU from a ward setting or urgent admissions [2–4]. Postsurgical ICU care has substantially higher costs than ward-level care with unclear benefits in terms of patient outcomes [5–9]. Current evidence also shows that outcomes are influenced by timely access to ICU environments, which shows variation between and across countries that is likely partially reflective of systematic differences between ICU bed availability, critical care funding, healthcare structures, and ICU triage decision-making [10–12].

Two multicenter cohort studies in adult surgical patients demonstrated a wide variation in postoperative ICU admission. The European Surgical Outcomes Study (EUSOS) showed that planned postoperative ICU admission rates after noncardiac surgery were low (5–8%) with wide variation across 28 countries (rates ranging from 1.2 to 16.1%) [4]. The International Surgical Outcomes Study (ISOS) showed that 9.7% of elective cardiac and noncardiac surgical patients were admitted across 27 low-, middle-, and high-income countries [13]. Importantly, both studies evaluated ICU admission in cohorts consisting of a wide range of different surgical procedures. This heterogeneous combination of procedures is problematic since the included procedures varied in complexity, patient type, risk of postoperative complications, and inherent need for postoperative ICU care.

To help address this important limitation in the literature, we conducted a population-based cohort study in the province of Ontario in Canada to assess the incidence and determinants of postoperative ICU admission among different types of noncardiac surgical procedures.

Methods

Settings and data sources

The methods and reporting of results for this study adhere to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines (www.strobe-statement.org). After receiving research ethics board approval from Sunnybrook Health Sciences Centre, we conducted a prospectively defined study using population-based administrative healthcare databases in Ontario, Canada. We used the Registered Persons Database (RPDB), Vital Statistics, Ontario census to extract demographics, socioeconomic status, and mortality. The Canadian Institute of Health Information Discharge Abstract Database (CIHI-DAD) was used to identify all hospital admissions, while the Ontario Health Insurance Plan (OHIP) captured all physician service claim data. Specialized and well-validated databases (i.e., Ontario Diabetes Database, Asthma, Congestive Heart Failure, Chronic Obstructive Pulmonary Disease, Ontario Hypertension Database) were used to identify specific comorbidities [14–19]. Data were linked using unique anonymized identifiers. Variables and codes used are summarized in Supplementary Tables 1 and 2.

Take-home message

There is a wide variation in ICU utilization between and within major noncardiac surgical procedures. The admitting hospital is the strongest determinant of postoperative ICU admission in adult surgical patients.

Study cohort

We identified adult patients (at least 40 years old) who underwent select major elective noncardiac surgeries between 2006 and 2014 in Ontario hospitals that had level 2 (i.e., noninvasive ventilation and/or limited end-organ support) and level 3 (i.e., mechanical ventilation and full hemodynamic support) ICU facilities. Thirteen surgical procedure groupings were included: open abdominal aortic aneurysm (AAA), endovascular aortic aneurysm repair (EVAR), peripheral arterial disease (PAD) procedures (above/below knee amputation, lower limb revascularization), open pneumonectomy or lobectomy, video-assisted thoracoscopic (VATS) lobectomy, upper gastrointestinal procedures (partial liver resection, biliary bypass, Whipple's resection, gastrectomy, esophagectomy), lower gastrointestinal (i.e., colorectal) resection, nephrectomy, hysterectomy, neurosurgical procedures (open craniotomy, posterior fossa surgery), femur, spine, and joint (total hip and knee) replacement surgery. These procedures were selected because they are common intermediate- and high-risk surgeries performed by most acute care hospitals. We included the first procedure in patients who underwent multiple surgeries during the study time frame. Any patient with a preoperative ICU admission, intraoperative death, and interhospital transfer prior to surgery were excluded. Low volume hospitals (less than 50 cases of individual procedures during the study period) were excluded to allow more precise estimates of hospital-specific rates of ICU use.

Outcome

The primary outcome was early postoperative ICU admission, defined as admission on the same day or within 24 h after the end of the index surgery. Patients who did not meet this definition were initially admitted to a general ward after surgery. Some of these same individuals may have subsequently been admitted to an ICU more than 24 h postsurgery, which were defined as "late ICU admissions". Our definition of early ICU admission was chosen because it captured patients with planned postsurgical admissions, as well as patients who unexpectedly required ongoing advanced monitoring or treatment that was commenced in the operating room.

ICU admissions were identified by the validated special care unit (SCU) code in the CIHI-DAD. The SCU code has a date (recorded YYYYMMDD) and time (recorded HHMM, 24-h clock) indicator, which allows identification of ICU admission and discharge. Reporting of the SCU code is mandatory in Ontario and previous validation studies have shown good accuracy (sensitivity of 92–97%, specificity greater than 99%, positive predictive values 84–99%, negative predictive value greater than 99%) [20, 21]. Surgical interventions are recorded in CIHI-DAD using the Canadian Classification of Health Interventions (CCI) codes with a date/time stamp. Accuracy of reporting surgery type is high (sensitivity 95%, positive predictive value 91%), while the date of surgery has 97% agreement with re-abstracted studies [22, 23].

Covariates

Patient demographics (i.e., age, sex) were identified using the RPDB. The Charlson comorbidity index score and individual comorbidities (i.e., coronary artery disease, atrial fibrillation, myocardial infarction, heart failure, diabetes mellitus, hypertension, chronic obstructive pulmonary disease, PAD, stroke, hemi- or paraplegia, chronic renal insufficiency, dialysis, asthma, dementia, malignancy, liver disease, rheumatologic diseases) were extracted from CIHI-DAD using ICD-10 diagnostic codes and Ontario comorbidity-specific databases within 3 years before surgery. Type and duration of surgical procedures were extracted from CIHI-DAD. Hospital bed numbers and teaching status were obtained from the information about Ontario healthcare institutions database.

Statistical analysis

The postoperative discharge destination (ward, early ICU, and late ICU), postoperative length of stay, and mortality were described using median (interquartile range, IQR) for continuous variables and frequency (percentage) for categorical variables. Patients admitted early to ICU were compared to those initially admitted to a general ward (including those with late ICU admissions) using standardized differences.

The unadjusted hospital-specific proportion of patients admitted early to ICU and exact binomial 95% confidence interval were calculated for each surgical group. To understand the extent to which postoperative ICU admission use for different surgical procedures was correlated within the same individual hospital, Spearman correlation coefficients were calculated to characterize the association of the proportions of patients admitted early to ICU across different surgery types within hospitals. Coefficients less than 0.4 were considered low, 0.4–0.7 medium, and greater than 0.7 strong correlation [24].

Multivariable logistic regression models were developed for each surgical group to characterize the adjusted association of hospital factors (teaching status, ICU capacity, procedure-specific surgical volume), patient characteristics (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 mellitus, liver disease, hypertension, cerebrovascular disease, atrial fibrillation), and duration of surgery with early ICU admission. ICU capacity, characterized by the ratio of ICU beds to total hospital beds, was assessed using a three-knot restricted cubic spline to account for possible non-linearity with the log-odds of early ICU admission [25]. The regression model was estimated using generalized estimating equation (GEE) methods to account for clustering of patients within hospitals. Forest plots were used to present the adjusted odds ratios for individual covariates from these procedure-specific regression models.

To characterize the impact of the individual hospital on the probability of early ICU admission across hospitals, the intraclass coefficient (ICC) and median odds ratio (MOR) were calculated using the estimated variance of the random intercepts from a hierarchical random effects logistic regression model. These models were separately estimated for each surgical group using the same patient- and hospital-level covariates listed previously. 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 is adjusted for patient-level covariates [26]. It is the median value obtained when comparing the adjusted odds of early postoperative ICU admission if the same individual underwent surgery at two different randomly selected hospitals. The MOR compares higher-ranked versus lower-ranked hospitals and thus always has a value of at least 1.

Model discrimination was described using the c-statistic, while calibration was assessed using Loess-based calibration plots [27]. Multicollinearity was defined by a variance inflation factor greater than 5. Analyses were conducted using SAS v.9.4 (SAS Institute, Cary, US) and R statistical software (v.0.98.1091 www.rstudio.org, R Core Team 2014). Two-sided p values less than 0.05 were considered statistically significant.

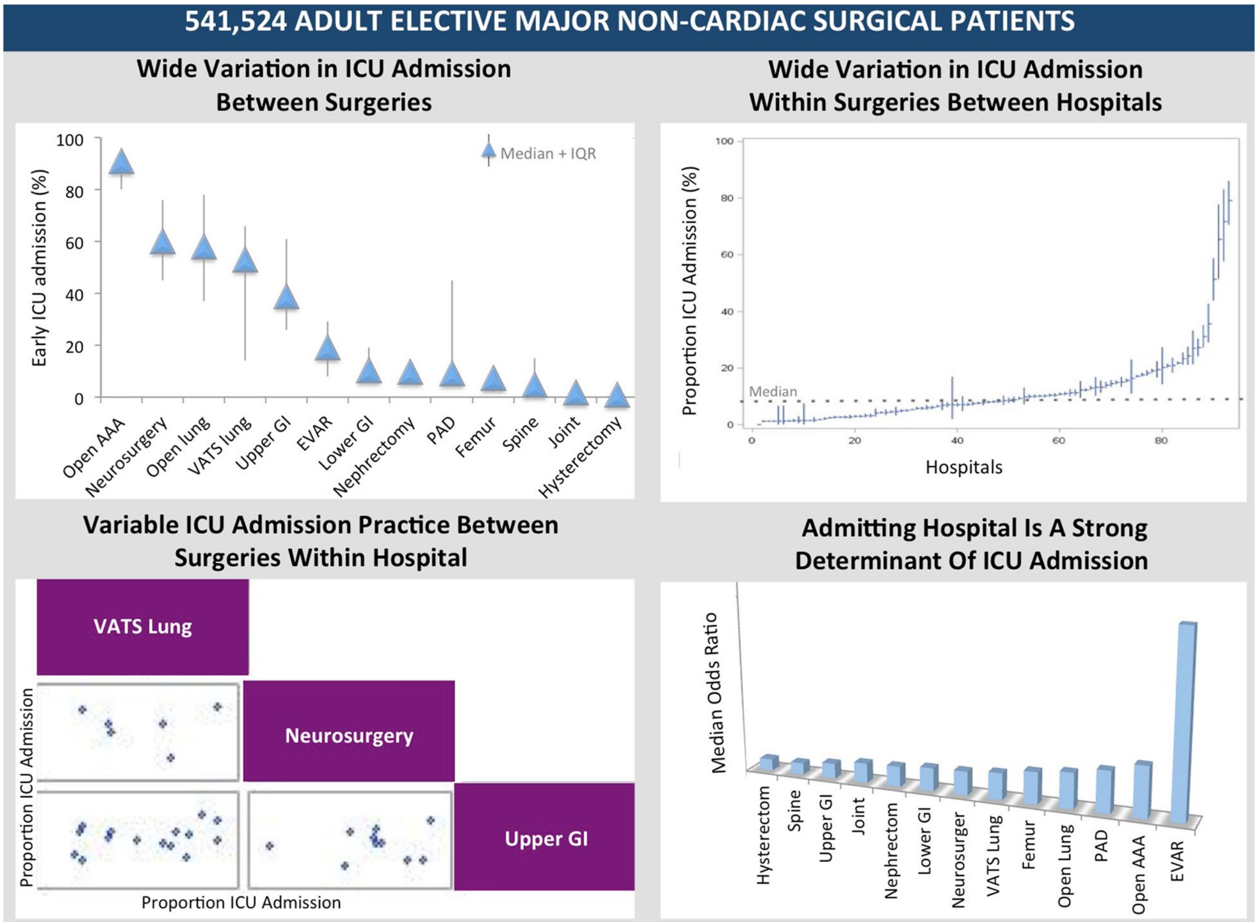

Fig. 1 Summary of main study findings

Results

The cohort included 541,524 patients across 93 Ontario hospitals. The postoperative discharge destination for all patients is summarized in Supplementary Fig. 1. In total, 10.6% of patients ($n = 57{,}251$) were admitted to ICU at any time after surgery, with 52,063 (9.6%) early admissions and 5188 (1.0%) late admissions. Among the majority of patients (89.4%) who were never admitted to an ICU, the 30-day mortality risk was 0.2% and median postoperative length of stay was 4 (IQR 3–5) days. In contrast, early ICU admission patients had a 30-day mortality risk of 2.4% and length of stay of 6 (IQR 4–9) days. Compared to early ICU admissions, late ICU admission was associated with a higher 30-day (11.6%) mortality risk and longer length of stay (13 days, IQR 8–23). A total of 2830 (0.5%) patients died within 30 days postsurgery with 964 (34.1%) patients never admitted to ICU at any stage during their hospital stay.

Perioperative characteristics of early ICU admissions showed that patients were generally older, had more comorbidities, and underwent longer-duration procedures in large hospitals in comparison to patients initially admitted to the ward (Tables 1 and 2). As would be expected for a sicker patient group, the unadjusted postoperative length of stay and mortality were higher among patients admitted early to ICU.

The hospital-specific proportions of patients admitted early to ICU after surgery were high for open AAA repair, lung resection, and neurosurgery (Table 3 and Supplementary Fig. 2). The remaining surgeries had lower average rates of early ICU admission with considerable interhospital variation. There was generally low within-hospital correlation with respect to the rates of early ICU admission across different surgeries (Supplementary Fig. 3). Higher positive correlations were evident among procedures that are typically performed by the same surgical specialty such as lower and upper gastrointestinal surgery (commonly performed by general surgeons) and

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
Age (years)	65 (55–73)	68 (60–76)	65 (55–74)	0.28
Female	315,470 (64.5%)	23,355 (44.9%)	338,825 (62.6%)	0.40
Atrial fibrillation	11,105 (2.3%)	3343 (6.4%)	14,448 (2.7%)	0.20
CAD	17,318 (3.5%)	5514 (10.6%)	22,832 (4.2%)	0.28
Hypertension	299,201 (61.1%)	36,874 (70.8%)	336,075 (62.1%)	0.21
Myocardial infarction	6702 (1.4%)	2300 (4.4%)	9002 (1.7%)	0.18
PVD	6652 (1.4%)	3703 (7.1%)	10,355 (1.9%)	0.29
Stroke	4301 (0.9%)	1282 (2.5%)	5583 (1.0%)	0.12
Diabetes	109,081 (22.3%)	16,061 (30.8%)	125,142 (23.1%)	0.19
Asthma	75,283 (15.4%)	8436 (16.2%)	83,719 (15.5%)	0.02
COPD	85,541 (17.5%)	17,700 (34.0%)	103,241 (19.1%)	0.38
Chronic renal disease	4183 (0.9%)	1425 (2.7%)	5608 (1.0%)	0.14
Dialysis	1382 (0.3%)	446 (0.9%)	1828 (0.3%)	0.08
Chronic liver disease	1738 (0.4%)	572 (1.1%)	2310 (0.4%)	0.09
Primary cancer	21,454 (4.4%)	8646 (16.6%)	30,100 (5.6%)	0.41
Secondary cancer	15,948 (3.3%)	5949 (11.4%)	21,897 (4.0%)	0.32
Charlson score ≥ 2	50,702 (10.4%)	17,231 (33.1%)	67,933 (12.5%)	0.57
Rural residence	76,183 (15.6%)	7882 (15.1%)	84,065 (15.5%)	0.01

Numbers reported as *n* (%) and median (interquartile range)

CAD coronary artery disease, *COPD* chronic obstructive pulmonary disease, *ICU* intensive care unit, *PVD* peripheral vascular disease

spine, femur, and joint replacement surgeries (performed by orthopedic surgeons).

The adjusted association of patient-, surgery-, and level factors with early ICU admission are summarized separately for each group in Supplementary Fig. 4 and Table 3. Increasing patient age was associated with increased adjusted odds of early ICU admission for lung, open AAA, nephrectomy, femur, hysterectomy, upper and lower gastrointestinal surgeries. Male sex was only associated with higher odds of admission for joint replacement surgery. Patient comorbidities and Charlson comorbidity index scores of at least 2 were associated with increased odds of early ICU admission in surgeries with generally lower overall rates of early ICU admission (i.e., lower gastrointestinal, nephrectomy, hysterectomy, joint replacement, spine surgery). Teaching hospital status was not associated with early ICU admission, except for upper gastrointestinal surgery, where it was associated with reduced odds of ICU admission. The relationship between ICU bed capacity and odds of early ICU admission was highly variable with no consistent pattern (Supplementary Fig. 5). Several surgeries (i.e., nephrectomy, upper gastrointestinal, PAD) showed increased odds of early ICU admission with rising percentage of ICU beds, while other surgeries (lung resection, lower gastrointestinal, neurosurgery) demonstrated a bell-shaped curve.

The individual admitting institution was a strong factor affecting ICU admission for all surgeries. The ICC values ranged from 18.0% for hysterectomy to 75.9% for EVAR, while the MOR values ranged from 2.3 to 21.5 (Table 4). All models displayed good discrimination and reasonable calibration on Loess plots with no evidence of multicollinearity. Main study findings have been summarized in Fig. 1.

Discussion

This population-based cohort study in the most populous Canadian province assessed the incidence and determinants of early postoperative ICU admission for 13 elective noncardiac surgical groups. When these surgeries were considered collectively, the proportion of patients admitted to ICU in Ontario is twice that of European centers (9.6 vs. 5%) but similar to the global average (9.7%) reported in the ISOS study [4, 13]. This direct comparison of ICU admission rates should be interpreted cautiously since the EUSOS and ISOS studies included a small number of lower-complexity (e.g., breast surgery) and cardiac surgical procedures. Interestingly, the 30-day mortality among patients admitted early to ICU in our study is similar to the in-hospital mortality of patients admitted to ICU in the ISOS and EUSOS studies (ca. 2%), albeit with a slightly longer ICU length of stay (1.8 vs. 1 day) [4]. Late ICU admissions formed approximately 1% of the study cohort, which is similar to the proportion of unplanned ICU admissions in the EUSOS study

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
Surgery				
Open AAA	1734 (0.4%)	5692 (10.9%)	7426 (1.4%)	0.47
EVAR	3432 (0.7%)	1253 (2.4%)	4685 (0.9%)	0.14
Femur	1378 (0.3%)	74 (0.1%)	1452 (0.3%)	0.03
Hysterectomy	102,063 (20.9%)	1634 (3.1%)	103,697 (19.1%)	0.57
Joint	271,519 (55.5%)	8654 (16.6%)	280,173 (51.7%)	0.88
Lower GI	48,188 (9.8%)	9195 (17.7%)	57,383 (10.6%)	0.23
Nephrectomy	11,056 (2.3%)	1714 (3.3%)	12,770 (2.4%)	0.06
Upper GI	6630 (1.4%)	4710 (9.0%)	11,340 (2.1%)	0.35
Open lung resection	4444 (0.9%)	6336 (12.2%)	10,780 (2.0%)	0.47
VATS lobectomy	4334 (0.9%)	3843 (7.4%)	8177 (1.5%)	0.33
Neurosurgery	2485 (0.5%)	3366 (6.5%)	5851 (1.1%)	0.33
PAD	7789 (1.6%)	2668 (5.1%)	10,457 (1.9%)	0.2
Spine	24,409 (5.0%)	2924 (5.6%)	27,333 (5.0%)	0.03
Duration surgery (min)	123 (98–166)	205 (140–287)	127 (100–178)	0.9
Hospital				
Teaching hospital	176,521 (36.1%)	24,801 (47.6%)	201,322 (37.2%)	0.24
Total beds	277 (192–355)	305 (219–447)	284 (196–360)	0.27
Surgical beds	68 (45–125)	85 (55–170)	70 (45–127)	0.27
ICU beds	21 (14–40)	27 (18–64)	22 (14–49)	0.34
Proportion ICU beds	9 (7–12)	10 (7–13)	9 (7–12)	0.28
Outcomes				
30-day MR	1565 (0.3%)	1265 (2.4%)	2830 (0.5%)	0.18
90-day MR	3255 (0.7%)	2189 (4.2%)	5444 (1.0%)	0.23
Postoperative LOS	4 (3–5)	6 (4–9)	4 (3–5)	0.81

Numbers reported as *n* (%) and median (interquartile range)

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

[4]. A US study evaluated ICU utilization and outcomes for five elective surgeries [6]. We showed similar high probabilities of ICU admission after open AAA repair (Ontario 90.8% vs. USA 92%) but lower probabilities of ICU admission after EVAR (Ontario 19.3% vs. USA 52.6%) and upper GI procedures (Ontario 39.1% vs. USA 71.4–80%). The lower ICU admission probabilities is likely attributable to fewer ICU beds (12.9 vs. 22 beds per 100,000) and ICU admissions (389 vs. 1999 admissions per 100,000) in Canada versus the USA [5, 11].

Our study found a wide variation in the probability of postoperative ICU admission in Ontario. The individual admitting hospital was a strong determining factor that accounted for a large proportion of the observed interhospital variation across all surgeries and often exceeded the magnitude of almost all patient-level risk factors. The influence of clinically sensible patient factors (e.g., comorbidity burden) was greatest among surgeries with generally lower overall probabilities of ICU admission (general, orthopedic, and urogynecological procedures). In contrast, preoperative health status and local ICU capacity had less influence on procedures with high rates of ICU admission such as open AAA repair, open lung resection, and neurosurgery. It is likely that probabilities for ICU admission were high in these specific procedures because they are perceived as consistently more complex (e.g., higher blood loss and cardiovascular stress), regardless of the underlying health status of the patient.

The considerable interhospital variation in probabilities of ICU admission is, in part, explained by the absence of guidelines on which patients and noncardiac surgical procedures should be admitted postoperatively to ICU. In the absence of such guidance, local organizational and cultural factors are likely to determine whether patients are managed in ICUs after surgery. The close within-hospital correlation in ICU admission rates among surgeries performed by the same surgical specialty is consistent with the local culture being a strong driving force for ICU

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) [range]	Total volume of surgical procedures[a]	Number hospitals	Postoperative LOS, days median (IQR)	30-day mortality (%)	90-day mortality (%)
Open AAA	90.8 (80.0–94.4) [15.1–98.6]	7426	26	7 (6–9)	184 (1.9)	258 (3.5)
EVAR	19.3 (8.1–28.9) [1.3–95.2]	4685	13	2 (1–4)	48 (1.0)	92 (2.0)
Open lung	58.4 (36.6–78.1) [10.4–96.4]	10,780	27	6 (4–8)	203 (1.9)	409 (3.8)
VATS lung	52.8 (13.5–66.2) [2.6–80.6]	8177	18	3 (2–5)	62 (0.8)	143 (1.8)
Neurosurgery	60.3 (45.2–76.0) [7.7–87.2]	5851	11	3 (2–6)	146 (2.5)	485 (8.3)
Upper GI	39.1 (25.7–60.5) [2.2–82.3]	11,340	29	8 (6–11)	231 (2.0)	442 (3.9)
Lower GI	10.2 (6.2–19.0) [1.3–95.0]	57,383	87	6 (4–9)	835 (1.5)	1361 (2.4)
Nephrectomy	9.8 (7.0–14.2) [0.7–86.4]	12,770	48	4 (3–6)	94 (0.7)	196 (1.5)
Spine	4.7 (4.1–15.2) [1.2–34.6]	27,333	21	3 (2–6)	86 (0.3)	178 (0.7)
Joint	1.6 (0.8–4.2) [0.08–12.9]	280,173	66	4 (3–5)	574 (0.2)	1072 (0.4)
Femur	7.3 (1.9–9.7) [1.4–13.0]	1452	11	5 (3–8)	41 (2.8)	99 (6.8)
PAD	9.2 (6.3–45.1) [0.9–88.0]	10,457	32	5 (3–8)	218 (2.1)	460 (4.4)
Hysterectomy	0.9 (0.5–1.8) [0.07–14.4]	103,697	80	3 (2–3)	108 (0.1)	249 (0.2)

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

[a] Total number of patients over the entire time frame of the study

triage decision-making. Aside from culture, other local factors that are likely to influence ICU admission include surgical volumes, number and experience of nursing staff in surgical wards, presence of hospital critical care outreach teams, availability of remote telemetry monitoring systems, and financial reimbursement models for providers who manage postoperative ICU areas. Notably, local ICU bed capacity was inconsistently associated with the probability of ICU admission across different procedures. This variable association might be explained, in part, by interhospital differences in the ability to monitor patients for prolonged periods in the postoperative recovery unit, and presence of other services (e.g., trauma, cardiac surgery, transplantation) competing for the same pool of ICU beds.

The large effect of individual hospitals on ICU admission has not been well documented for surgical ICU patients. Nonetheless, the large between-hospital variation observed in our study is consistent with previous research in medical ICU patients [28–30]. For example, Admon et al. [28] showed that the individual hospital accounted for 17.6% of the variation in ICU admission for five common medical diagnoses (pneumonia, heart failure, myocardial infarction, stroke, chronic obstructive pulmonary disease) and one surgical procedure (hip arthroplasty) across 1120 US hospitals.

This study has several strengths including the use of a large population-based sample and well-validated datasets. Additionally, unlike some previous research, we minimized the influence of between-procedure heterogeneity by reporting patterns separately for different procedures. This approach was supported by the findings that different surgeries had considerably different patterns of ICU utilization within hospitals. Our study supports previous findings of wide variation in ICU admission for surgical patients among US hospitals reported by Wunsch et al. [6]. We also extended this prior research by including more complex surgeries and demonstrating a large hospital effect on ICU admission. Given that our data sources captured accurate timing of ICU admission, we could also specifically study patients who received ICU care early postsurgery. This study is set in a single-payer publically funded healthcare system. The results will interest many healthcare teams and policymakers in similar healthcare structures and where practice variation has implications on variation in cost of care (ICU bed CAN$3592 vs. ward bed CAN$1135) [5]. We anticipate that these findings will stimulate organizations to look at local drivers of ICU admission and differences in surgical practice patterns. Additional quantitative research required to assess these issues includes determining local ICU bed availability, characteristics of general ward nursing (e.g., number, experience, proportion of permanent versus agency staff), ward capabilities for providing postoperative treatments that require close monitoring (e.g., insulin and epidural infusions), postoperative resources (e.g., physician availability to manage postsurgical issues, access to critical care response teams), and capabilities of postoperative care units in providing prolonged monitoring and cardiorespiratory

Table 4 Intraclass 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[a]	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

ICC and MOR calculated using a hierarchical random effects logistic regression model after adjusting for 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, duration of surgery, teaching hospital status, ICU capacity, surgical volume of specific procedure being considered

AAA abdominal aortic aneurysm, *EVAR* endovascular abdominal aortic aneurysm repair, *PAD* peripheral arterial disease, *VATS* video-assisted thoracic surgery

[a] The high values for EVAR are likely due to the small number of procedures and hospitals undertaking this surgery with a wide range (1.3–95.2%) in proportion of patients admitted early to ICU. When the average intercept of − 1.9534 and estimated variance of random effect of 10.3420 obtained from the hierarchical model were used, the probability of early ICU admission for 95% of hospitals undertaking EVAR surgery ranged from 0.0003 to 0.9873

support. This quantitative research should be complemented by qualitative studies that explore local attitudes surrounding postsurgical care, and decision-making processes when ICU facilities are full. This will provide greater insights into potential mechanisms underlying interhospital variation in postoperative ICU utilization.

This study also has several limitations. First, our administrative data sources cannot distinguish a planned ICU admission from an unplanned admission resulting from an acute intraoperative event. However, unexpected major intraoperative complications that necessitate unexpected ICU admissions in the first 24 h are uncommon; hence, the majority of the early ICU admissions in this cohort likely consisted of planned postoperative ICU admissions. Second, administrative data do not capture certain relevant information such as blood loss or physiological data (e.g., blood pressure). Third, impact of ward staffing on ICU admission was not assessed since our data sources lacked information on the numbers, type, and experience of surgical ward staff.

With such a wide variation in ICU utilization across hospitals and surgical specialties, identifying whether postsurgical ICU care improves outcomes is vital given the high volume of patients undergoing surgery and cost of ICU care [5, 31]. Current evidence shows that the benefits of postoperative ICU care in terms of outcomes remains debatable. Wunsch et al. [6] showed no reduction in mortality in hospitals with higher ICU usage for select surgeries. The ISOS study also showed no survival benefit of hospital-specific rates of ICU admission, albeit in a heterogeneous cohort of cardiac and noncardiac procedures [7]. Several medical ICU utilization studies conducted in US hospitals have shown varied effects on outcomes [32, 33]. However, these medical and surgical studies are limited by heterogeneity of the study population and insufficient information regarding organizational factors. Furthermore, the relatively high numbers of ICU beds and admissions in US hospitals affect the generalizability of these results to other healthcare systems.

Conclusions

The proportion of patients admitted postoperatively to ICU varies considerably across different surgical procedures and hospitals, with the individual hospital being a critical determinant of whether patients were admitted to an ICU setting. These findings highlight the need for further research to identify hospital-level determinants of ICU admission, assess whether ICU care improves postoperative outcomes, and establish criteria for postoperative ICU admission.

Electronic supplementary material

The online version of this article (https://doi.org/10.1007/s00134-018-5330-6) contains supplementary material, which is available to authorized users.

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