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ASA Physical Status, Anesthetic Technique, and ICU Admission After Elective Surgery in Older Adults: A Prospective Multicenter Indonesian Cohort

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ABSTRACT

Background. Postoperative intensive care unit (ICU) beds are scarce in Indonesia while the number of older surgical patients grows.

Objective. We quantified postoperative ICU admission among older adults undergoing elective surgery and its association with American Society of Anesthesiologists (ASA) physical status and anesthetic technique.

Methods. Prospective cohort of consecutive patients aged ≥ 60 years undergoing elective non-cardiac surgery in 15 Indonesian tertiary hospitals (February–April 2021). Proportions with Wilson 95% confidence intervals (CI), exact and trend tests were computed from the recorded outcome-by-predictor tables. Because predictors were not cross-classified, adjusted associations were bounded across all 4,207,140 datasets consistent with the recorded margins and within clinically plausible limits.

Results. Of 893 patients, 168 (18.8%; 95% CI 16.4–21.5) were admitted to the ICU. Admission rose from 10.4% in ASA II to 31.5% in ASA III and 84.6% in ASA IV (trend $p < 0.001$); the adjusted odds ratio (OR) for ASA III versus II was at least 2.84 in every admissible dataset. Admission was 23.0% after general and 10.6% after regional anesthesia (crude OR 2.51, 95% CI 1.66–3.79). The ASA-adjusted OR ranged from 0.95 to 243 across all datasets, but from 1.82 to 6.74 when general-anesthesia use differed by ≤ 20 percentage points between ASA strata; with comorbidity added, the lowest value found was 1.34. ASA $\geq$ III identified 63.7% of admissions.

Conclusion. ASA physical status is robustly associated with postoperative ICU admission in older Indonesians. Excess admission after general anesthesia persists under plausible case-mix scenarios but cannot be separated from the unrecorded surgical procedure.

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1. Introduction

Surgical services are treating growing numbers of older patients with complex health needs. In the UK SNAP-3 cohort of 7,129 patients aged ≥ 60 years, multimorbidity and frailty were common and were associated with postoperative morbidity.¹ A Singaporean tertiary center documented a decade in which older patients became an ever larger share of general-surgical practice while their 30-day mortality fell from 5.8% to 2.7%, showing the importance of organized perioperative support.² In Indonesia, community studies in Jakarta found frailty in 14.7% of adults aged ≥ 60 years, closely linked to multimorbidity,³ and national insurance data show that hospital outpatient and inpatient visits for chronic cardiovascular disease fell by 39% and 28% at the onset of the COVID-19 pandemic.⁴

Older surgical patients carry a vulnerability that chronological age captures poorly. Across intensive care cohorts of surgical patients, 39.4% were frail, and frailty more than doubled short- and long-term mortality (risk ratio 2.66 for both).⁵ Frailty measured with the Clinical Frailty Scale raises postoperative mortality fourfold (odds

ratio [OR] 4.01) and doubles the risk of delirium (OR 2.47).^{6,7} Asian cohorts show the same pattern: among 302 older Vietnamese patients undergoing elective gastroenterological surgery, 18.5% were frail and frailty increased 30-day adverse outcomes more than sixfold (OR 6.56),⁸ and among 4,684 older Chinese patients undergoing elective non-cardiac surgery, frailty raised major complications from 16.7% to 21.5%.⁹ In the UK SNAP-3 cohort of 7,129 patients aged ≥ 60 years, multimorbidity, present in 63.1%, increased postoperative morbidity (adjusted OR 1.46) without affecting mortality, whereas frailty increased both.¹ These data explain why surgeons and anesthesiologists use postoperative critical care as a safety net for older patients.

Critical care is, however, the scarcest perioperative resource in middle-income Asian health systems. Before the pandemic, low- and lower-middle-income Asian economies had a median of 2.3 critical care beds per 100,000 population,¹⁰ and although capacity in the region rose to 9.4 beds per 100,000 by 2022, middle-income systems remained well below high-income ones.¹¹ Modelling for Bali projected that 1,831 patients would need ICU beds at the peak of the first COVID-19 wave against roughly 446 available.¹² The value of routine

postoperative ICU admission is itself uncertain. In two million elective operations in Japan, postoperative ICU admission was not associated with in-hospital mortality for 12 non-cardiovascular procedures;¹³ in a Spanish multicenter colorectal cohort, critical care admission after elective surgery (34.6% of patients) was not associated with better outcomes;¹⁴ and an international prospective analysis of elective surgery across 27 countries found no association between postoperative critical care admission and improved survival.¹⁵ Surgical high-dependency care can safely replace ICU care for selected patients.¹⁶

Anticipating which older patients will need an ICU bed matters for patients and health systems. The ASA physical status classification is a widely available preoperative risk descriptor associated with comorbidity burden¹⁷ and immediate postoperative ICU admission.¹⁸ Its reliability depends on the assessor: studies report inter-rater variation, including an international survey of surgeons and anesthesiologists in hepato-pancreato-biliary surgery.^{19,20,21} Prediction models reach areas under the curve of 0.80–0.92 but often use intraoperative or procedure-specific variables that may be unavailable when ICU beds are booked.^{22,23,24,25} Observational studies report more ICU admission after general than after neuraxial anesthesia,^{26,27} whereas randomized trials in older adults have not shown clear advantages of spinal or regional anesthesia for mortality, ambulation or delirium.^{28,29,30} This difference requires consideration of confounding by indication.

Indonesian evidence comes from multicenter perioperative studies conducted in teaching hospitals in 2021. Among 1,621 older surgical patients in 14 hospitals, postoperative ICU care (OR 2.70) and a Charlson Comorbidity Index above 3 (OR 2.33) were associated with 30-day mortality;³¹ 30-day mortality reached 38.6% among older ICU patients during February–May 2021;³² and in 933 older patients undergoing elective surgery, 59.8% received general anesthesia and anesthetic technique was associated with the change in postoperative quality of life.³³ The present cohort was assembled within the Indonesian Anesthesiology and Intensive Care (KATI) research collaboration during the same period, but its analysis population (893 consecutive elective patients) and its outcome differ from those of the published analyses: none of them examined which older patients were admitted to the ICU after elective surgery, and none could separate the influence of physiological status from that of anesthetic choice.

This study therefore had four aims: to estimate the incidence of postoperative ICU admission among older adults undergoing elective non-cardiac surgery in Indonesian tertiary hospitals and compare it with published benchmarks; to quantify its association with ASA physical status, anesthetic technique and comorbidity; to determine how robust the adjusted associations are to the joint distribution of these predictors, which was not available for analysis, both across all compatible datasets and within clinically plausible limits; and to derive the design parameters for a confirmatory study. We hypothesized that the ASA gradient would be robust and that the association with general anesthesia would be at least partly attributable to case-mix.

2. Methods

2.1 Study design

This was a prospective, multicenter, observational cohort study conducted within the KATI research collaboration and reported in accordance with the STROBE recommendations for cohort studies. ICU admission and its associations with ASA class, comorbidity and anesthetic technique were the prespecified analyses; the bounds, plausible-region, triage, benchmark and power analyses described below are exploratory.

2.2 Ethical approval

The study was approved by the CMHC Research Center Indonesia Ethics Committee (approval No. 2024/8442), which approved the present analysis of the prospectively collected, de-identified multicenter dataset in 2024. Written informed consent was obtained from every participant or a legally authorized representative at enrollment. The study was conducted in accordance with the Declaration of Helsinki.

2.3 Setting and participants

Fifteen tertiary referral hospitals in major Indonesian cities participated, with coordination from Dr. Saiful Anwar Regional General Hospital, Malang. All patients aged ≥ 60 years who were scheduled for elective non-cardiac surgery under anesthesia between 1 February and 30 April 2021 were invited consecutively. The only exclusion criterion was refusal or inability to provide informed consent. Emergency procedures and cardiac surgery were not eligible. Data collection took place during the COVID-19 pandemic, when ICU capacity in participating hospitals was shared with critically ill patients with COVID-19; COVID-19 status at the time of surgery was not part of the analysis dataset.

2.4 Variables and definitions

The primary outcome was postoperative ICU admission, recorded as a binary variable at the end of the anesthetic episode. The decision to admit was made by the attending surgical and anesthesia team according to the patient's clinical status and institutional protocols; planned and unplanned admissions were not distinguished, and ICU length of stay and organ support were not recorded. ASA physical status (I–V) was assigned preoperatively by the attending anesthesiologist; no ASA V patient was enrolled. Comorbidity was recorded as the presence of at least one pre-existing chronic condition; because the same conditions inform the ASA class, the two variables are expected to be positively associated. The Charlson Comorbidity Index was calculated on the case report form, but the scores were not available for the present analysis. Anesthetic technique was classified as general anesthesia, including planned combined general–regional techniques, or regional anesthesia, comprising spinal anesthesia, epidural anesthesia and major peripheral nerve blocks used as the primary technique. Age, sex and body mass index (BMI, kg/m²) were also recorded. The surgical procedure, specialty and duration were not part of the analysis dataset.

2.5 Data collection and analysis dataset

Trained research personnel at each center entered data into a secure web-based REDCap database, and records were de-identified before analysis. No patient had missing data for the outcome or the primary predictors. The

analysis was performed on the frequency tables of ICU admission by each recorded predictor (two-way outcome-by-predictor tables) exported from the study database, together with the mean and standard deviation of age; the patient-level record linking the predictors with one another was not available to the analysis team. Cell counts were reconciled to the recorded proportions (to one decimal place, $N=893$) by exhaustive integer search. The search returned a unique set of counts for ASA class, anesthetic technique and ICU admission; four compatible group sizes for comorbidity (614, 615, 621 or 622 patients with comorbidity), all of which were analyzed; and no recoverable cross-tabulation of sex by ICU admission, for which only the recorded p value (0.060) was available.

2.6 Study size

The sample size was determined by consecutive enrollment over three months in 15 hospitals. With 168 events, the cohort provides more than 40 events per parameter for the four-parameter categorical ASA model and estimates the ICU admission proportion to within ± 2.6 percentage points (95% CI half-width). The power of this sample size to detect adjusted associations of anesthetic technique was assessed by simulation (Section 2.9).

2.7 Statistical analysis of the observed tables

Proportions are reported with 95% Wilson score CIs. The sex ratio was compared with parity using an exact binomial test. Published ICU admission proportions were presented as descriptive benchmarks. Because age, surgical mix and admission definitions differed, no hypothesis tests or pooled effect estimates were used for these external comparisons. Associations between ICU admission and each predictor were tested with Fisher's exact and Pearson χ^2 tests and summarized as odds ratios (Woolf 95% CI), relative risks (log-method 95% CI), risk differences (Newcombe 95% CI), Cohen's h , and phi or Cramér's V . The ASA gradient was tested with the Cochran-Armitage trend test and with logistic regression treating ASA either as a linear per-class term or as categorical; departure from linearity was tested by the residual deviance and by the Akaike information criterion (AIC). The performance of ASA thresholds as rules for anticipating ICU admission was described by sensitivity, specificity, predictive values, likelihood ratios and the Youden index, and the discrimination of the four-level ASA class by the area under the receiver operating characteristic curve (AUC), with a Hanley-McNeil CI that is approximate for an ordinal predictor with ties. Because the outcome was common (18.8%), the E -value was computed for the relative risk rather than the odds ratio of ICU admission after general anesthesia, to quantify the strength of unmeasured confounding needed to explain the association away.³⁴

2.8 Sensitivity analysis over the space of datasets consistent with the observed margins

Because ASA class, technique and comorbidity were not cross-classified with each other, adjusted associations could not be estimated directly. Instead of imputing the missing joint distribution, we determined the range of adjusted estimates compatible with the recorded data. For the two-predictor analysis, every three-way ASA $\times$ technique $\times$ ICU table that reproduces both recorded two-way margins was enumerated: within each outcome stratum the ASA-by-technique table has fixed row and column totals, giving 954 admissible configurations among admitted and 4,410 among non-admitted patients, and

4,207,140 complete tables. Two maximum-likelihood logistic models were fitted to each table by Newton-Raphson iteration with step-halving (convergence: maximum score component $<10^6$): Model 2, the primary model, with ASA categorical (ASA II reference) plus technique, and Model 1 with ASA as a linear per-class term plus technique, retained for comparability with the original study protocol. For each coefficient we recorded the attainable minimum and maximum OR, the distribution across tables and the number of tables in which the Wald test reached $p < 0.05$. Because admissible tables are not equally likely, these counts are descriptive rather than probabilities; we therefore also report the distribution weighted by the probability of each table under random assignment of technique within outcome strata (hypergeometric weights), which corresponds to technique being independent of ASA class. The ASA-technique imbalance in each table was expressed as the difference in the proportion receiving general anesthesia between ASA III–IV and ASA I–II patients, which identified the tipping point at which the technique association lost significance, and the analysis was repeated within plausible regions in which this imbalance did not exceed 10 or 20 percentage points.

For the three-predictor model (ASA per class, technique and comorbidity), the $4 \times 2 \times 2$ joint distribution within each outcome stratum was free subject to all recorded one-way margins. Firth-penalized logistic regression was fitted to 4,000 random label assignments per admissible comorbidity group size, and the extremes of each coefficient were sought by steepest-ascent search using margin-preserving swaps of technique or comorbidity labels between patients, started from 16 constructed and 6 random configurations per target. The search was repeated within a clinically plausible region in which the technique imbalance across ASA groups did not exceed 20 percentage points, comorbidity was 0 to 60 percentage points more prevalent in ASA III–IV than in ASA I–II patients, and comorbidity prevalence differed by no more than 20 points between techniques (10 random admissible starts per target, 40 for the technique extremes). Because local search cannot guarantee global optima, extremes are reported as the most extreme values reached, together with the number of starts reaching them. For sex, all 169 sex-by-ICU tables compatible with the margins were enumerated (S_0), and the single table whose p value rounds to the recorded 0.060 under a standard test was reported as a labeled reconstruction (S_1), not as an observed result. A measure whose attainable range excluded the null was considered robust to the unrecorded joint distribution; a range spanning the null was reported as an association that the recorded data cannot identify. Because the odds ratio is non-collapsible, adjusted ORs were interpreted with the expectation that adjustment for a strong prognostic factor inflates them even without confounding.³⁵

2.9 Power simulation and software

To inform a confirmatory study, power for the ASA-adjusted technique coefficient was estimated by Monte Carlo simulation (1,000 cohorts per scenario; Monte Carlo standard error ≤ 1.6 percentage points) using the observed ASA distribution and general anesthesia in 66% of patients. ASA-specific intercepts were calibrated so that the simulated admission rate in each ASA class reproduced the observed rate for each target OR (1.3, 1.5, 1.75 and 2.0). Two scenarios were simulated: technique independent of

ASA (balanced) and general anesthesia 18 percentage points more frequent in ASA III–IV than in ASA I–II patients (confounded), an imbalance within the plausible region defined above. All tests were two-sided with $\alpha=0.05$, and *p* values are reported to three decimal places. Analyses were performed in Python 3.14.6 with NumPy 2.4.4, SciPy 1.18.1 and statsmodels 0.15.0; figures were drawn with Matplotlib 3.10.8. The analysis code is available from the corresponding author.

3. Results

3.1 Participants

A total of 893 patients were enrolled and analyzed, none being excluded for missing outcome or predictor data

(Figure 1). Their characteristics are presented in Table 1 and Figure 2. The mean age was 67.4 ± 6.2 years, and 464 patients (52.0%; 95% CI 48.7–55.2) were women, a ratio compatible with parity (exact binomial $p=0.255$). ASA physical status was II in 567 patients (63.5%), III in 305 (34.2%), I in 8 (0.9%) and IV in 13 (1.5%), so that 318 patients (35.6%) were classified ASA III–IV. Between 614 and 622 patients (68.8–69.7%) had at least one comorbidity. General anesthesia was used in 592 patients (66.3%; 95% CI 63.1–69.3) and regional anesthesia in 301 (33.7%), of whom 272 (90.4%) received spinal anesthesia, 22 (7.3%) epidural anesthesia and 7 (2.3%) a peripheral nerve block.

Table 1. Characteristics of 893 patients aged ≥ 60 years undergoing elective non-cardiac surgery in 15 Indonesian tertiary hospitals.

Characteristic	n (%)	95% CI*
Patients	893	—
Age, years, mean $\pm$ SD	67.4 ± 6.2	mean 67.0–67.8
Female sex	464 (52.0)	48.7–55.2
Male sex	429 (48.0)	44.8–51.3
ASA physical status I	8 (0.9)	0.5–1.8
ASA physical status II	567 (63.5)	60.3–66.6
ASA physical status III	305 (34.2)	31.1–37.3
ASA physical status IV	13 (1.5)	0.9–2.5
Comorbidity present†	614–622 (68.8–69.7)	65.6–72.6
General anesthesia‡	592 (66.3)	63.1–69.3
Regional anesthesia	301 (33.7)	30.7–36.9
Spinal	272 (30.5; 90.4 of regional)	27.5–33.6
Epidural	22 (2.5; 7.3 of regional)	1.6–3.7
Peripheral nerve block	7 (0.8; 2.3 of regional)	0.4–1.6
Postoperative ICU admission	168 (18.8)	16.4–21.5

Notes: *Wilson score interval for proportions (percentage points); t-based interval for the mean age. †The reported percentages are compatible with four group sizes (614, 615, 621 or 622); the interval shown is the union of their 95% CIs. ‡Includes planned combined general–regional anesthesia. Sex ratio versus parity: exact binomial $p=0.255$; Cohen's $h=0.039$. ASA, American Society of Anesthesiologists; ICU, intensive care unit; SD, standard deviation.

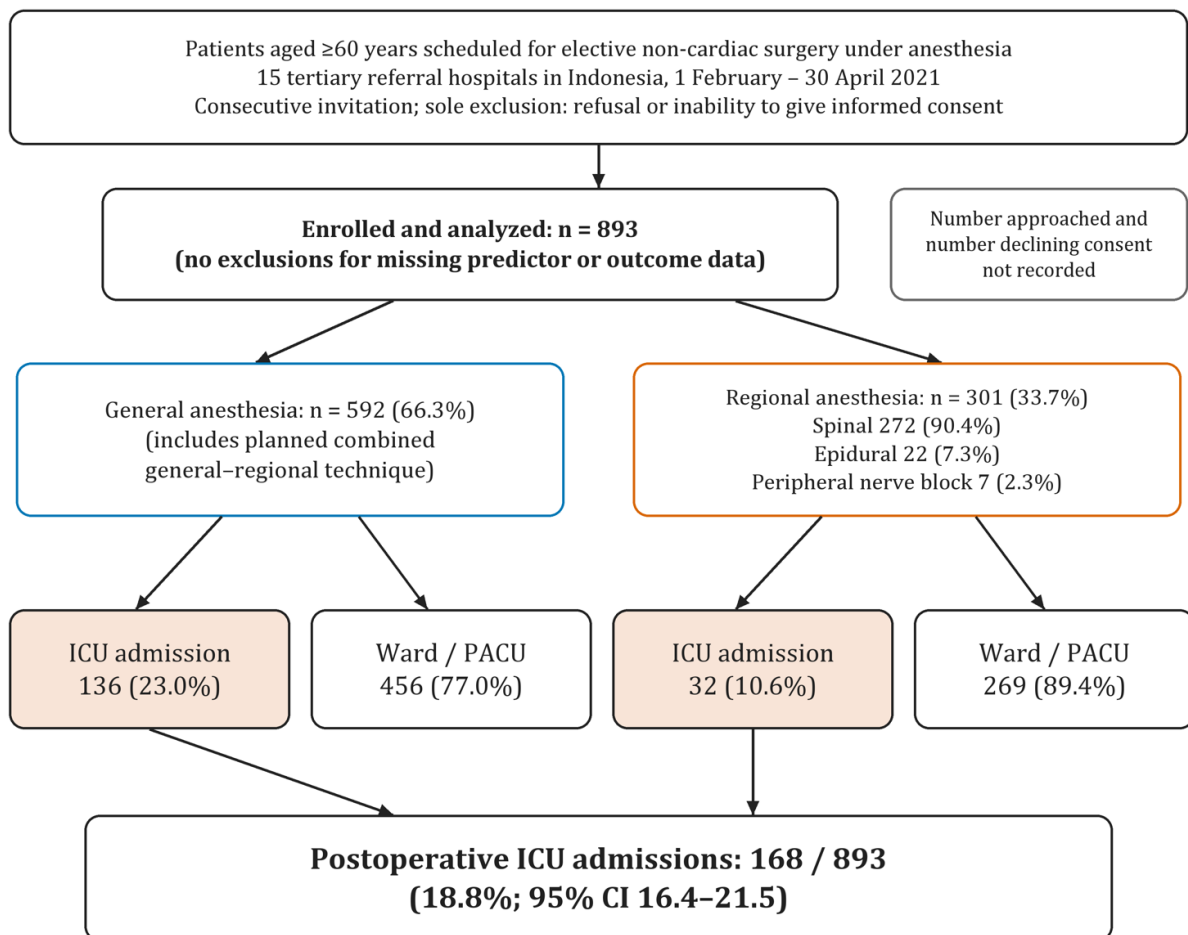


Figure 1. STROBE flow diagram of the cohort. Percentages of ICU admission are within each anesthetic-technique group. PACU, post-anesthesia care unit.

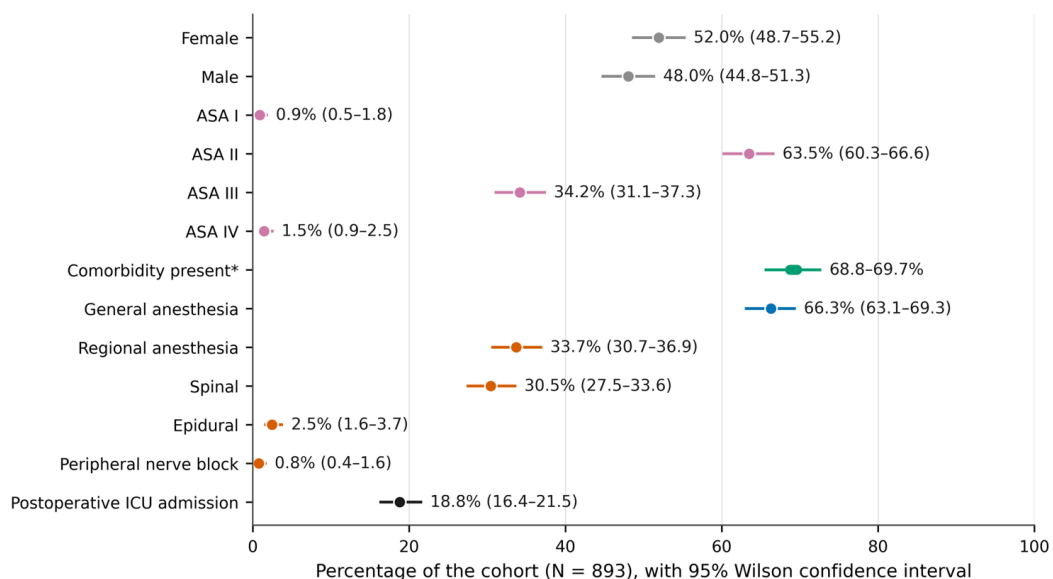


Figure 2. Composition of the cohort with 95% Wilson confidence intervals (N=893). For comorbidity, the thick bar spans the four group sizes compatible with the recorded percentages and the thin bar the union of their 95% CIs.

3.2 Incidence of postoperative ICU admission

Postoperative ICU admission occurred in 168 patients (18.8%; 95% CI 16.4–21.5). Averaged across the 15 hospitals and three months, this corresponds to 19.8 older elective patients and 3.7 postoperative ICU admissions per hospital per month.

3.3 ASA physical status

ICU admission increased steeply with ASA class (Table 2, Figure 3): 59 of 567 ASA II patients (10.4%; 95% CI 8.2–13.2), 96 of 305 ASA III patients (31.5%; 26.5–36.9) and 11 of 13 ASA IV patients (84.6%; 57.8–95.7) were admitted. Compared with ASA II, the OR was 3.95 (95% CI 2.75–5.68; $p < 0.001$) for ASA III and 47.36 (10.25–218.83; $p < 0.001$) for ASA IV, with risk differences of 21.1 and 74.2

percentage points. Two of the eight ASA I patients (25.0%; 7.1–59.1) were admitted, which did not differ from ASA II (OR 2.87, 0.57–14.54; $p=0.204$). The overall association was strong ($\chi^2(3)=95.31$, $p<0.001$; Cramér's $V=0.327$) and monotone across ASA II–IV (Cochran–Armitage $z=8.97$, $p<0.001$). A linear per-class logistic term gave an OR of 4.05 (95% CI 2.93–5.61) but fitted the observed gradient poorly (residual deviance 8.03 on 2 df, $p=0.018$; AIC 28.6 vs 24.6

for categorical coding), because it underestimated admission at both ends of the scale; restricted to ASA II–IV, the gradient was linear (per-class OR 4.39, 3.15–6.13; linearity $p=0.139$). Patients classified ASA III–IV were admitted three times as often as those classified ASA I–II (33.6% vs 10.6%; OR 4.27, 3.00–6.08; risk difference 23.0 percentage points, 95% CI 17.3 to 28.9).

Table 2. Postoperative ICU admission by ASA physical status and anesthetic technique (observed two-way tables).

Group	Patients, n	ICU, n (%)	95% CI, %	OR (95% CI)	Risk difference, points (95% CI)	p	Cohen's h
ASA I	8	2 (25.0)	7.1–59.1	2.87 (0.57–14.54)	14.6 (–3.5 to 48.7)	0.204	0.39
ASA II (reference)	567	59 (10.4)	8.2–13.2	1.00	0	—	—
ASA III	305	96 (31.5)	26.5–36.9	3.95 (2.75–5.68)	21.1 (15.4 to 26.9)	<0.001	0.53
ASA IV	13	11 (84.6)	57.8–95.7	47.36 (10.25–218.83)	74.2 (47.2 to 85.5)	<0.001	1.68
ASA III–IV vs I–II	318 vs 575	107 (33.6) vs 61 (10.6)	28.7–39.0 vs 8.3–13.4	4.27 (3.00–6.08)	23.0 (17.3 to 28.9)	<0.001	0.57
General anesthesia	592	136 (23.0)	19.8–26.5	2.51 (1.66–3.79)	12.3 (7.2 to 17.0)	<0.001	0.34
Regional anesthesia (reference)	301	32 (10.6)	7.6–14.6	1.00	0	—	—

Notes: Odds ratios (Woolf 95% CI) and risk differences (Newcombe 95% CI, percentage points) are unadjusted, computed from the observed two-way tables; p values from Fisher's exact test; effect size is Cohen's h. ASA overall: $\chi^2(3)=95.31$, $p<0.001$; Cramér's $V=0.327$; Cochran–Armitage trend $z=8.97$, $p<0.001$. Per-class logistic OR 4.05 (95% CI 2.93–5.61); departure from linearity: deviance 8.03 on 2 df, $p=0.018$; AIC 28.6 (linear) vs 24.6 (categorical); ASA II–IV only: per-class OR 4.39 (3.15–6.13), linearity $p=0.139$. General vs regional anesthesia: relative risk 2.16 (1.51–3.09); $\chi^2(1)=19.90$; $p=0.019$; E-value for the relative risk 3.74 (confidence limit 2.38); 136 of the 168 admissions (81.0%) followed general anesthesia.

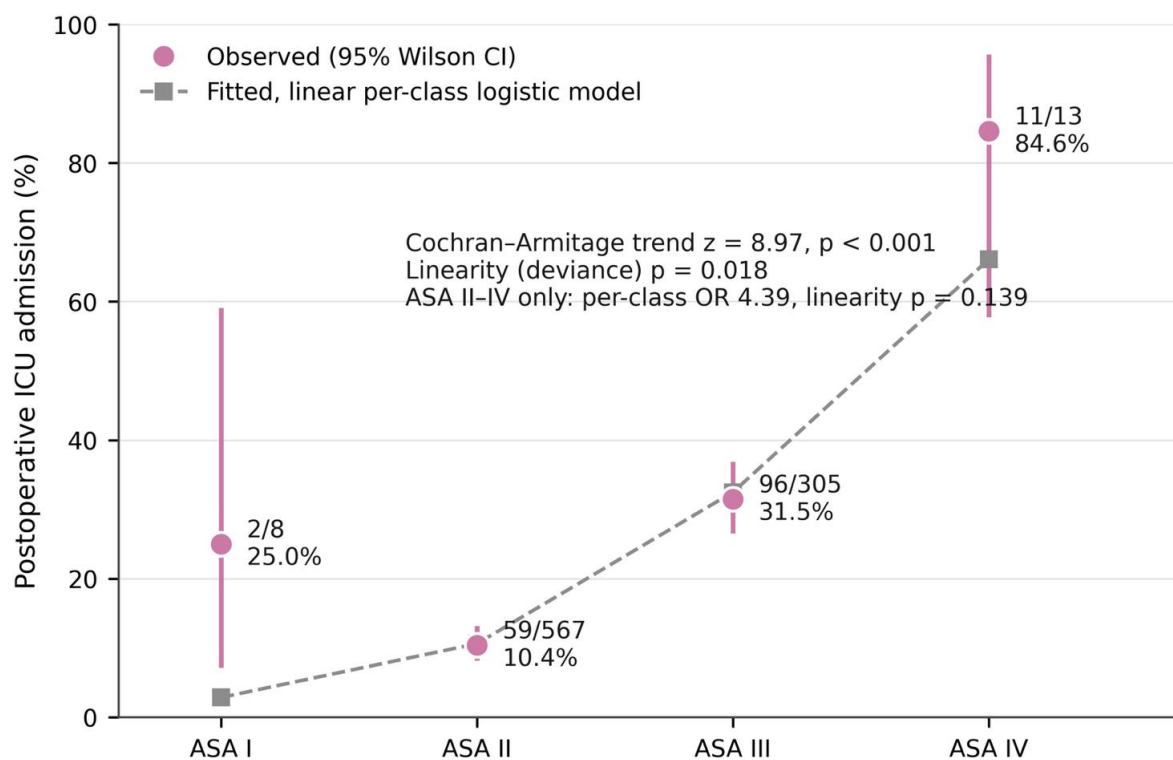


Figure 3. Postoperative ICU admission by ASA physical status. Circles show observed proportions with 95% Wilson confidence intervals and n/N; squares show the fit of a logistic model with ASA as a linear per-class term, which underestimates admission in ASA I and ASA IV. The gradient is strongly monotone from ASA II to ASA IV.

3.4 ASA physical status as an admission rule

Used as a rule for anticipating ICU admission (Table 3), ASA $\geq$ III flagged 318 patients (35.6%) and identified 107 of the 168 admissions (sensitivity 63.7%, 95% CI 56.2–70.6) with a specificity of 70.9% (67.5–74.1). One in three flagged patients was admitted (positive predictive value 33.6%), whereas 89.4% of unflagged patients were not (negative predictive value), corresponding to likelihood ratios of 2.19 and 0.51. In planning terms, an ASA $\geq$ III booking rule

would have pre-booked 7.1 patients per hospital per month, of whom 2.4 were admitted, while 1.4 admissions per hospital per month arose among unflagged patients. ASA IV was a strong but rare rule-in criterion (positive predictive value 84.6%; positive likelihood ratio 23.74, 95% CI 5.31–106.09) that captured only 6.5% of admissions. The four-level ASA class discriminated admitted from non-admitted patients with an AUC of 0.679 (95% CI 0.631–0.727), and 61 of the 168 admissions (36.3%) occurred in patients classified ASA I–II.

Table 3. Performance of ASA physical status thresholds as a rule for anticipating postoperative ICU admission.

Rule	Patients flagged, n (%)	Sensitivity, %	Specificity, %	PPV, %	NPV, %	LR+	LR–	Youden J
ASA $\geq$ II	885 (99.1)	98.8 (95.8–99.7)	0.8 (0.4–1.8)	18.8 (16.3–21.5)	75.0 (40.9–92.9)	1.00 (0.98–1.01)	1.44 (0.29–7.06)	-0.004
ASA $\geq$ III	318 (35.6)	63.7 (56.2–70.6)	70.9 (67.5–74.1)	33.6 (28.7–39.0)	89.4 (86.6–91.7)	2.19 (1.86–2.57)	0.51 (0.42–0.63)	0.346
ASA IV	13 (1.5)	6.5 (3.7–11.3)	99.7 (99.0–99.9)	84.6 (57.8–95.7)	82.2 (79.5–84.5)	23.74 (5.31–106.09)	0.94 (0.90–0.98)	0.063

Notes: Each row treats the stated ASA threshold as a rule for anticipating postoperative ICU admission (168 admissions, 725 non-admissions). Percentages with 95% Wilson CIs; likelihood ratios with log-method CIs. Area under the ROC curve for the four-level ASA class: 0.679 (95% CI 0.631–0.727, Hanley–McNeil). Of the 168 admissions, 61 (36.3%, 95% CI 29.4–43.8) occurred in ASA I–II patients. Averaged over 15 hospitals and 3 months, the cohort generated 19.8 older elective patients and 3.7 ICU admissions per hospital per month; an ASA $\geq$ III rule would flag 7.1 patients per hospital per month, of whom 2.4 were admitted, with 1.4 admissions per hospital per month among unflagged patients. LR, likelihood ratio; NPV, negative predictive value; PPV, positive predictive value.

3.5 Anesthetic technique, comorbidity, sex and body mass index

ICU admission followed 136 of 592 general anesthetics (23.0%; 95% CI 19.8–26.5) and 32 of 301 regional anesthetics (10.6%; 7.6–14.6), a risk difference of 12.3 percentage points (7.2–17.0), a relative risk of 2.16 (1.51–3.09) and a crude OR of 2.51 (1.66–3.79; Fisher $p < 0.001$; $\phi = 0.149$) (Table 2, Figure 4). General anesthesia therefore preceded 81.0% of all ICU admissions. The E-value for the relative risk was 3.74 (2.38 for its lower confidence limit).

Patients with comorbidity were admitted about twice as often as those without (21.9–22.0% vs 11.8–11.9%), with ORs of 2.09–2.10 and $p < 0.001$ in each of the four admissible group sizes (Table 4). The association of sex with ICU admission could not be identified: across the 169 admissible sex-by-ICU tables the OR for men ranged from 0.00 to 295, and the only reconstruction compatible with the recorded $p = 0.060$ corresponds to admission of 21.4% of men and 16.4% of women (OR 1.39, 0.99–1.95). The recorded p value for BMI was 0.555; BMI values were not available.

Table 4. Comorbidity, sex and body mass index in relation to postoperative ICU admission.

Variable / scenario	ICU in exposed, n/N (%)	ICU in reference, n/N (%)	OR (95% CI)	Risk difference, points (95% CI)	p	Effect size
Comorbidity, split 614/279	135/614 (22.0)	33/279 (11.8)	2.10 (1.39–3.17)	10.2 (4.8 to 14.9)	<0.001	0.120
Comorbidity, split 615/278	135/615 (22.0)	33/278 (11.9)	2.09 (1.38–3.15)	10.1 (4.8 to 14.8)	<0.001	0.119
Comorbidity, split 621/272	136/621 (21.9)	32/272 (11.8)	2.10 (1.39–3.18)	10.1 (4.8 to 14.9)	<0.001	0.119
Comorbidity, split 622/271	136/622 (21.9)	32/271 (11.8)	2.09 (1.38–3.17)	10.1 (4.7 to 14.8)	<0.001	0.118
Sex, all admissible tables (S0)*	female 0–168 of 464	male 0–168 of 429	0.00 to 295	—	<0.05 in 86.4% of tables	—
Sex, narrative-constrained (S1)†	male 92/429 (21.4)	female 76/464 (16.4)	1.39 (0.99–1.95)	5.1 (-0.1 to 10.2)	0.059	0.065
Body mass index	values not available	—	—	—	0.555 (as recorded)	—

Notes: Comorbidity: the four group sizes compatible with the recorded percentages (21.9% vs 11.8%) are shown separately; the inference is identical in all four. OR and risk difference (percentage points) compare patients with versus without comorbidity (or men versus women); p values from Fisher's exact test; V, Cramér's V. *The sex-by-ICU cross-tabulation was not available; S0 lists the range over all 169 tables consistent with the 464/429 and 168/725 margins. †S1 is the only admissible table whose p value rounds to the recorded $p = 0.060$ under a standard test (Fisher $p = 0.059$; Yates $p = 0.064$); it is a labelled sensitivity scenario, not an observed table.

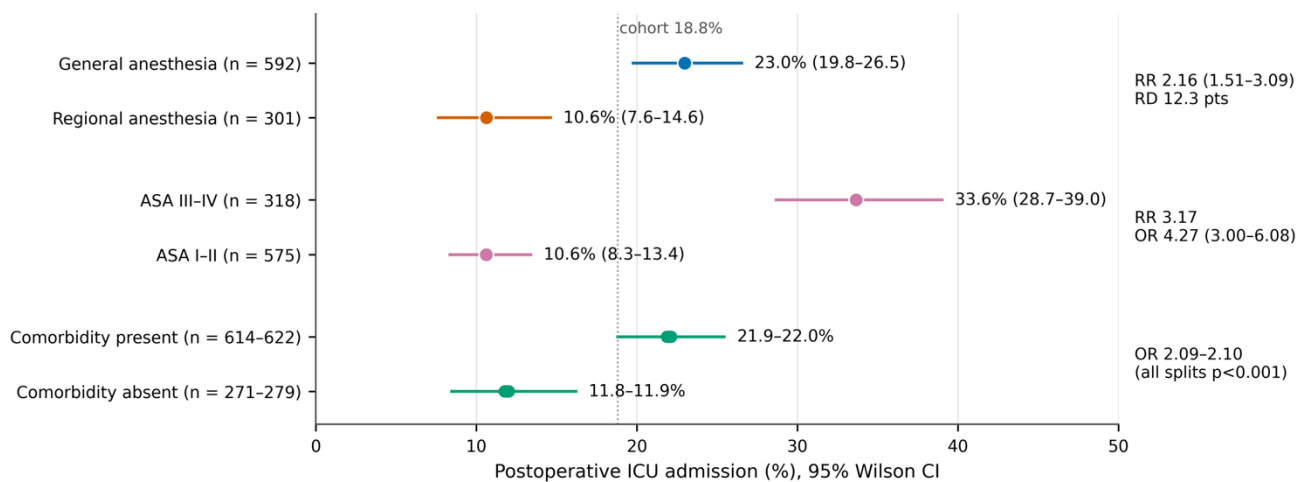


Figure 4. Postoperative ICU admission by anesthetic technique, ASA group and comorbidity, with 95% Wilson confidence intervals. For comorbidity, bars span the four admissible group sizes. The dotted line marks the overall admission rate (18.8%). RD, risk difference; RR, relative risk; OR, odds ratio (all unadjusted).

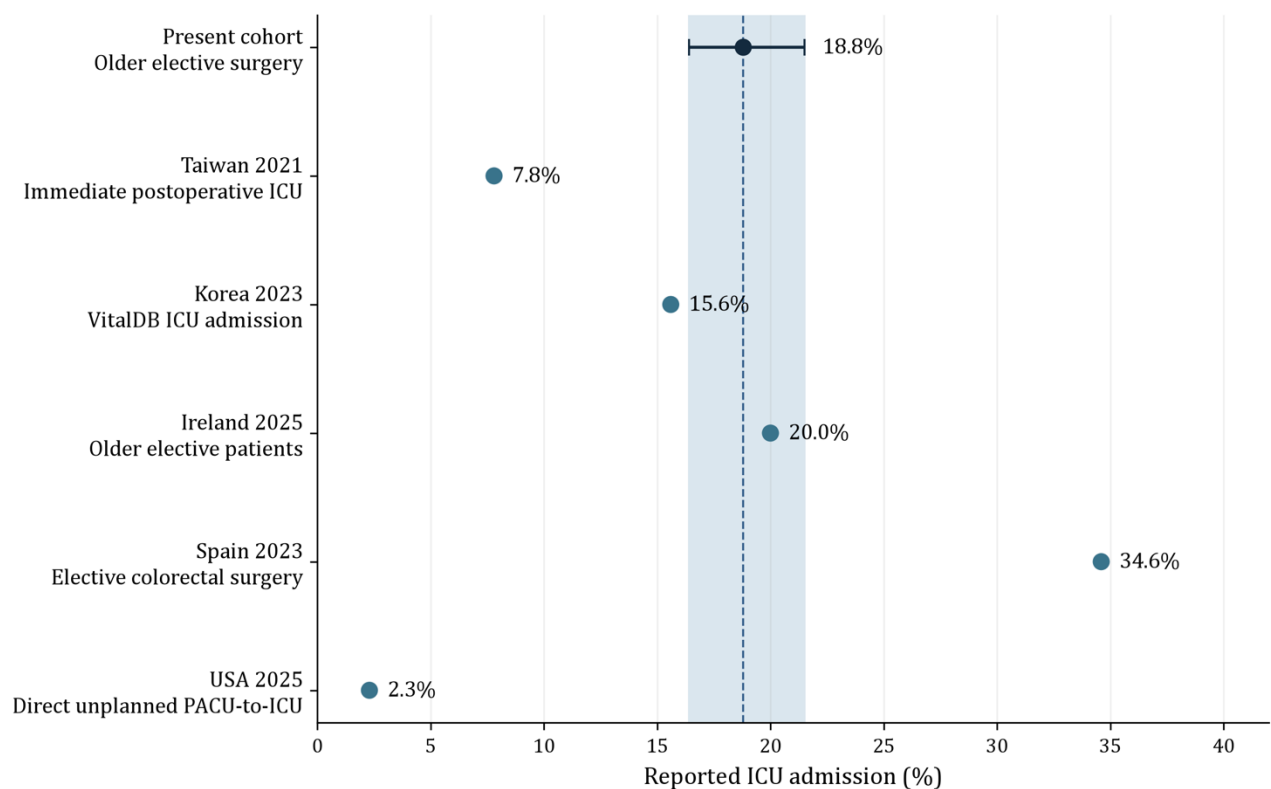


Figure 5. Descriptive ICU admission proportions.

3.7 Sensitivity analysis over datasets consistent with the observed margins

Across all 4,207,140 admissible ASA × technique × ICU tables (Table 5, Figure 6), the categorical model gave adjusted ORs of at least 2.84 for ASA III and at least 37.08 for ASA IV versus ASA II in every table; the linear model gave a per-class OR between 3.61 and 159.9, with a random-assignment-weighted median of 4.04 (2.5th–97.5th percentile 3.86–4.29). The ASA-adjusted OR for general versus regional anesthesia was at least 0.95 in both models, reached $p < 0.05$ in 95.4% of admissible tables in the categorical model (92.6% in the linear model) and was never significantly below 1; its random-assignment-weighted median was 2.51 (2.22–2.89) in the categorical

model. The technique association lost significance only in tables in which general anesthesia was used at least 30.4 percentage points more often in ASA III–IV than in ASA I–II patients (Figure 7). Within the plausible region of an imbalance of no more than 20 percentage points (1,642,788 tables), the technique OR ranged from 1.82 to 6.74 in the categorical model and from 1.85 to 5.10 in the linear model, was significant in every table, and the lowest lower 95% confidence limit in the linear model was 1.20; within 10 points (821,394 tables) it ranged from 2.11 to 5.26. When technique was balanced across ASA classes, the adjusted OR was 2.57–3.09, higher than the crude OR because of non-collapsibility. The smallest attainable standard error of the adjusted log-OR for technique was 0.218.

Table 6. Sensitivity analysis over every dataset consistent with the observed margins.

Model and predictor	Minimum adjusted OR	Maximum adjusted OR	Median (2.5–97.5th percentile), all tables	Median (2.5–97.5th percentile), random-assignment weighted*	Tables with $p < 0.05$, OR > 1 (%)	Tables with $p < 0.05$, OR < 1 (%)
All admissible tables (n = 4,207,140)						
Model 2: general vs regional anesthesia	0.95	not finite [†]	3.54 (1.48–31.2)	2.51 (2.22–2.89)	95.4	0.0
Model 2: ASA III vs II	2.84	not finite [†]	4.56 (3.15–30.9)	3.95 (3.76–4.21)	100.0	0.0
Model 2: ASA IV vs II	37.08	not finite [†]	71.22 (39.47–728.3)	47.56 (37.40–63.20)	100.0	0.0
Model 1: general vs regional anesthesia	0.95	243.0	3.27 (1.38–25.4)	2.49 (2.23–2.81)	92.6	0.0
Model 1: ASA, per class	3.61	159.9	4.67 (3.63–23.8)	4.04 (3.86–4.29)	100.0	0.0
Plausible region: technique imbalance ≤ 20 points (n = 1,642,788)						
Model 2: general vs regional anesthesia	1.82	6.74	—	—	100.0	0.0
Model 2: ASA III vs II	3.30	—	—	—	100.0	0.0
Model 1: general vs regional anesthesia	1.85	5.10	—	—	100.0	0.0
Model 1: ASA, per class	3.67	6.17	—	—	100.0	0.0
Plausible region: technique imbalance ≤ 10 points (n = 821,394)						
Model 2: general vs regional anesthesia	2.11	5.26	—	—	100.0	0.0
Model 1: ASA, per class	3.83	5.19	—	—	100.0	0.0

Notes: All 4,207,140 three-way ASA $\times$ technique $\times$ ICU tables that reproduce both observed two-way margins were enumerated, and a maximum-likelihood logistic model was fitted to each. Model 2 (primary): ASA categorical (ASA II reference) plus technique. Model 1: ASA as a linear per-class term plus technique, retained for comparability although it fits the observed ASA gradient poorly. Technique imbalance: absolute difference in the proportion receiving general anesthesia between ASA III–IV and ASA I–II patients. The percentages of tables reaching $p < 0.05$ are unweighted counts of admissible tables, not probabilities. *Weighted by the probability of each table under random assignment of technique within each ICU stratum (hypergeometric), i.e. technique independent of ASA given outcome. †In 126 tables the categorical-model estimate does not exist because of separation. Tipping point: technique was non-significant only in tables in which general anesthesia was used at least 30.4 percentage points more often in ASA III–IV than in ASA I–II patients; with technique balanced across ASA, the adjusted OR was 2.57–3.09. Within the ≤ 20 -point region the lowest lower 95% confidence limit of the Model 1 technique OR was 1.20. The smallest attainable standard error of the adjusted log-OR for technique was 0.218 (Model 1), compared with 0.211 for the crude 2×2 table.

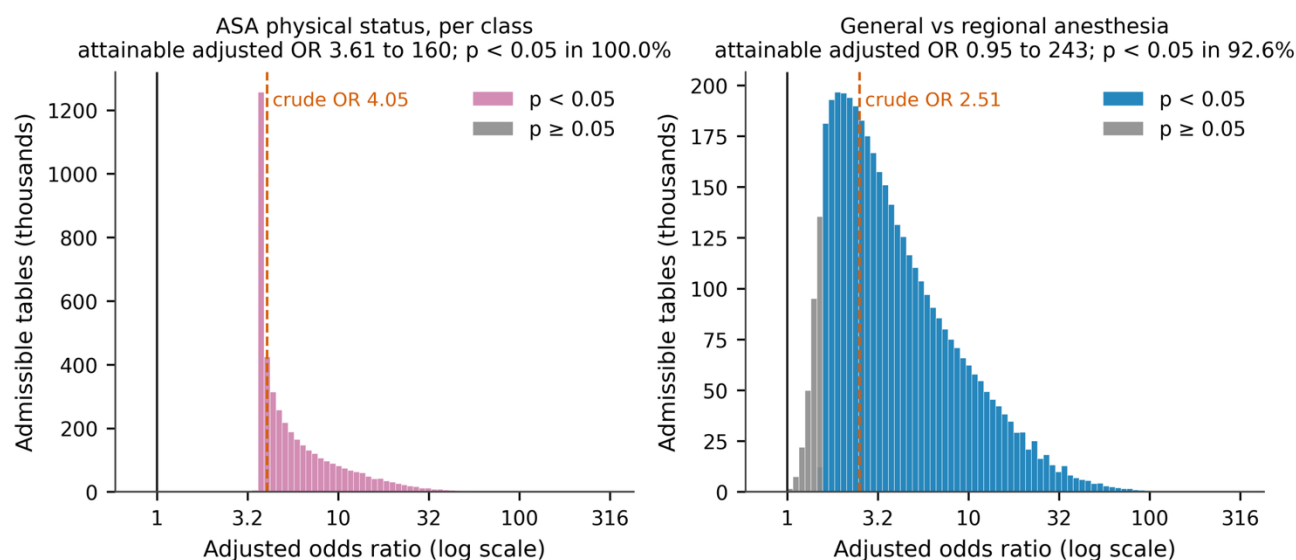


Figure 6. Distribution of the ASA-adjusted odds ratios across all 4,207,140 three-way tables consistent with the observed ASA-by-ICU and technique-by-ICU margins (Model 1: ASA per class plus technique). Colored bars: tables in which the adjusted estimate reached $p < 0.05$; grey bars: $p \geq 0.05$. The vertical black line is $OR=1$; the dashed line is the crude OR.

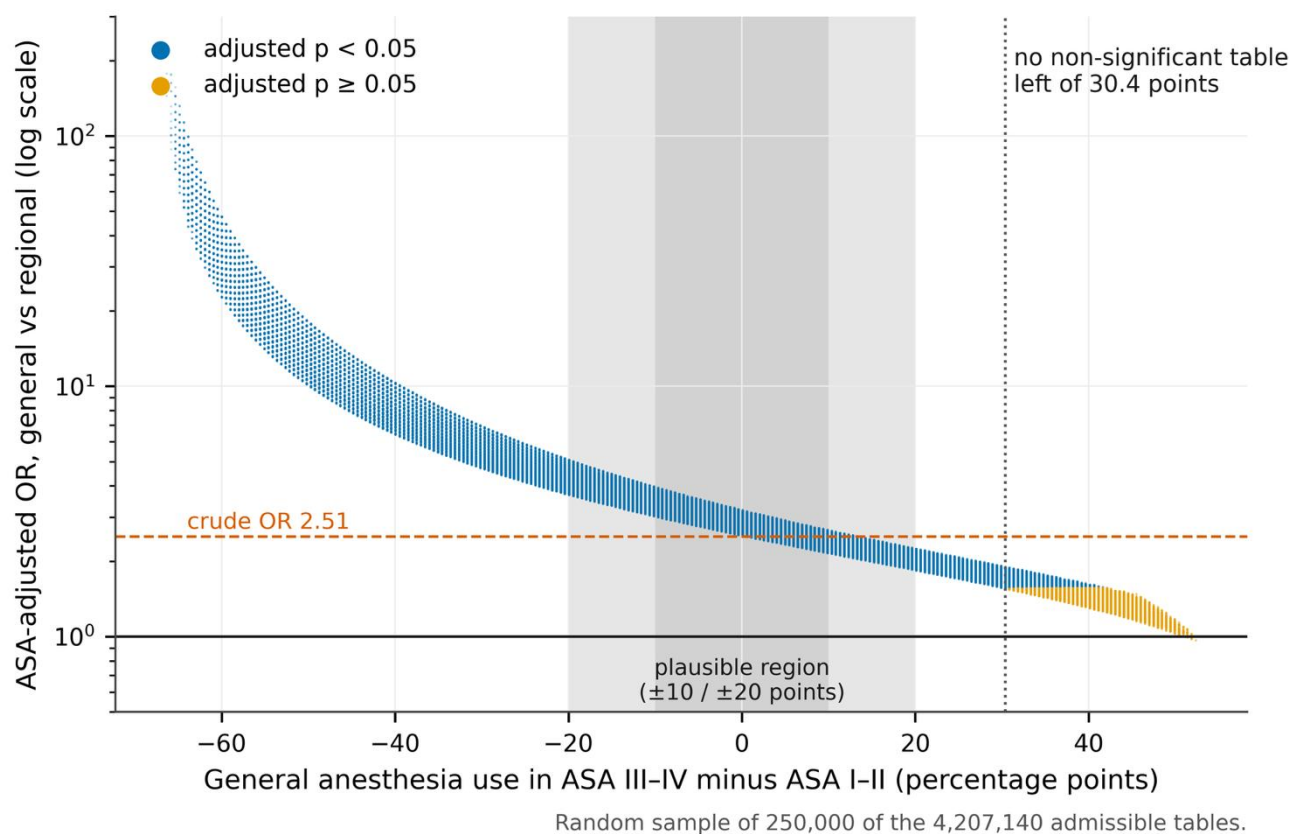


Figure 7. Tipping-point map for the association between general anesthesia and ICU admission. Each point is an admissible table (random sample of 250,000), placed by how much more often general anesthesia was used in ASA III–IV than in ASA I–II patients (x-axis) and by the resulting ASA-adjusted OR (Model 1, y-axis). Shaded bands mark the plausible regions of ± 10 and ± 20 percentage points. The association loses significance only when general anesthesia is concentrated in sicker patients by ≥ 30.4 percentage points.

When comorbidity was added as a third predictor (Table 6, Figure 8), the lowest ASA OR reached in the unrestricted search was 2.72, a minimum reached from 18 of 22 starting configurations, so that the ASA association remained above 1 in every configuration explored. The unrestricted technique OR ranged from 0.15 to above 10,000 and the comorbidity OR from below 0.01 to 3,522, extremes reached from only one or two starts and produced by near-separated configurations. Within the plausible region, the ASA OR ranged from 3.19 to 10.81, the technique OR from

1.34 to 11.82 (the five lowest solutions from 40 starts lay between 1.34 and 1.37), and the comorbidity OR from 0.42 to 7.00. Under random label assignment, the median ORs were 4.01 for ASA, 2.47 for technique and 2.06 for comorbidity, each significant in all draws. Thus the ASA association is robust under every scenario, the technique association is robust within the plausible region but not across all mathematically admissible datasets, and the adjusted comorbidity association cannot be identified.

Table 6. Three-predictor sensitivity analysis: attainable Firth-adjusted odds ratios for ASA physical status, anesthetic technique and comorbidity

Predictor	Lowest adjusted OR reached, unrestricted	Highest adjusted OR reached, unrestricted	Plausible region: lowest-highest reached*	Random assignment: median (2.5–97.5th percentile)	Random assignment: p<0.05 (%)
ASA, per class	2.72	>10,000	3.19–10.81	4.01 (3.77–4.32)	100
General vs regional anesthesia	0.15	>10,000	1.34–11.82	2.47 (2.18–2.82)	100
Comorbidity present vs absent	<0.01	3,522	0.42–7.00	2.06 (1.81–2.39)	100

Notes: Firth-penalized logistic regression with ASA (per class), technique and comorbidity, fitted to datasets in which every observed predictor-by-ICU margin is reproduced; the joint ASA × technique × comorbidity distribution within each ICU stratum is free. Values are pooled across the four admissible comorbidity group sizes (lowest minimum, highest maximum, mean of medians, outermost percentiles). Extremes are the most extreme values reached by steepest-ascent search from 16 constructed and 6 random starts per target (margin-preserving label swaps; all fits converged) and are therefore lower bounds on the attainable range. Convergence: in the unrestricted search the ASA minimum was reached from 18 of 22 starts, whereas technique and comorbidity extremes were reached from only 1–2 of 22 starts and arise from near-separated configurations. *Plausible region: technique imbalance across ASA groups ≤20 percentage points, comorbidity 0–60 points more prevalent in ASA III–IV than in ASA I–II, and comorbidity prevalence differing by ≤20 points between techniques; 10 random admissible starts per target and split (40 for the technique extremes; the five lowest technique solutions were 1.34–1.37). The random-assignment distribution (4,000 draws per comorbidity split) corresponds to predictors being mutually independent given ICU status.

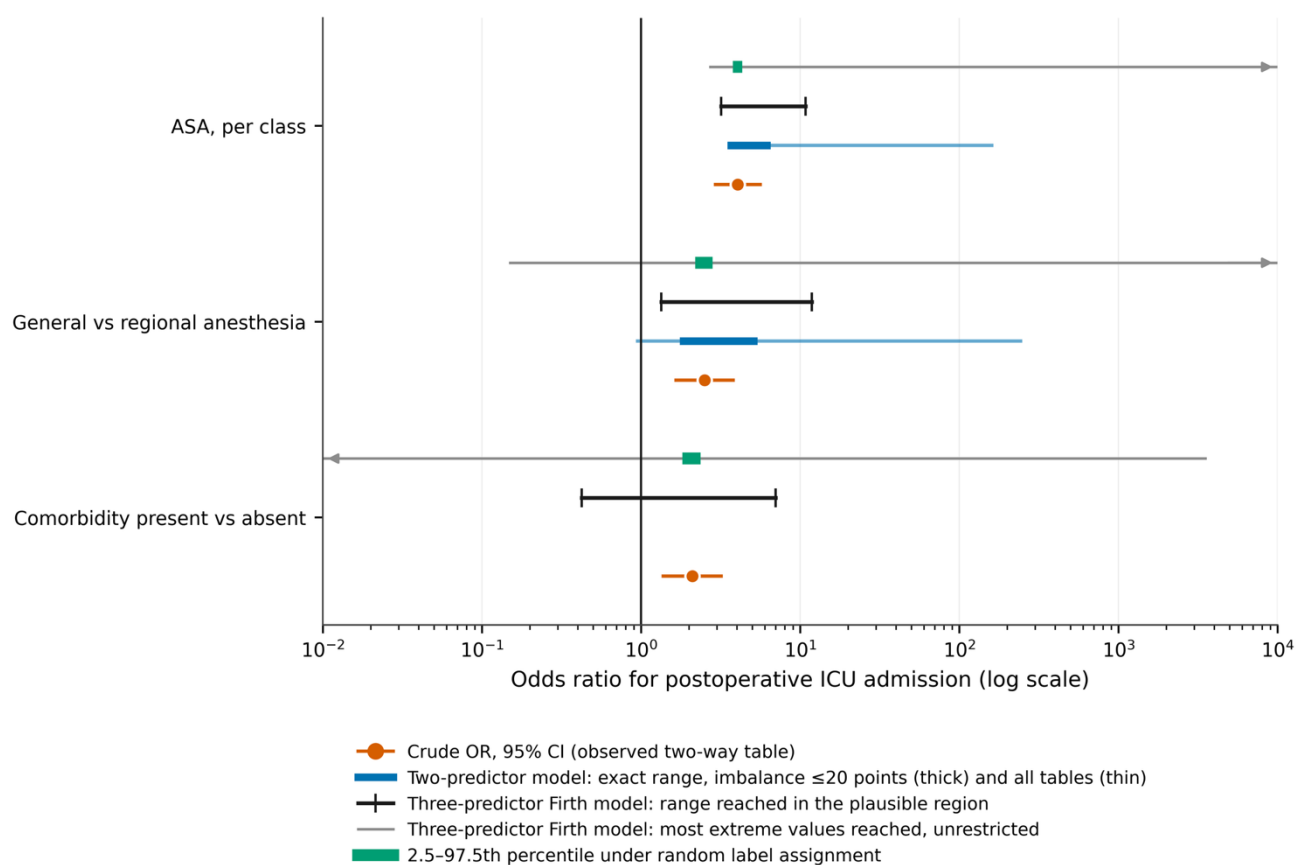


Figure 8. Crude and attainable adjusted odds ratios for the three recorded predictors. For each predictor, from bottom to top: crude OR with 95% CI from the observed two-way table; exact range in the two-predictor model across all admissible tables (thin) and within a technique imbalance of ≤20 percentage points (thick); range reached by the three-predictor Firth model within the plausible region; and the most extreme values reached by the unrestricted three-predictor search with the 2.5–97.5th percentile band under random label assignment. Arrows indicate values beyond the plotted range.

3.8 Power and design parameters

The present cohort had 51% power (49% under confounding) to detect an ASA-adjusted technique OR of

1.5 and 92% (89%) to detect an OR of 2.0 (Table 8, Figure 9). Detecting an OR of 1.5 with 80% power would require 1,690–1,860 patients, and an OR of 1.3 would require 3,900–4,250 patients.

Table 7. Power of the cohort and sample sizes required for a confirmatory study of anesthetic technique and postoperative ICU admission

Target ASA-adjusted OR	Power at n = 893 (balanced / confounded)	n for 80% power	n for 90% power	Expected ICU admissions at 80% power
1.3	26% / 23%	3,900 / 4,250	5,340 / 6,000	733 / 799
1.5	51% / 49%	1,690 / 1,860	2,250 / 2,540	318 / 350
1.75	78% / 76%	940 / 980	1,270 / 1,380	177 / 184
2.0	92% / 89%	620 / 700	810 / 920	117 / 132

Notes: Monte Carlo power (1,000 simulated cohorts per point) for a two-sided Wald test ($\alpha=0.05$) of the technique coefficient in a logistic model adjusted for ASA class (categorical), with the observed ASA distribution, ASA-specific ICU risks calibrated to the present cohort and general anesthesia in 66% of patients. Balanced: technique independent of ASA. Confounded: general anesthesia in 60% of ASA I–II and 78% of ASA III–IV patients. Sample sizes interpolated on the simulated grid and rounded to 10. Adjustment for further covariates correlated with technique (e.g. surgical magnitude) inflates the required n by approximately $1/(1-R^2)$, where R^2 is the proportion of technique variance explained by those covariates.

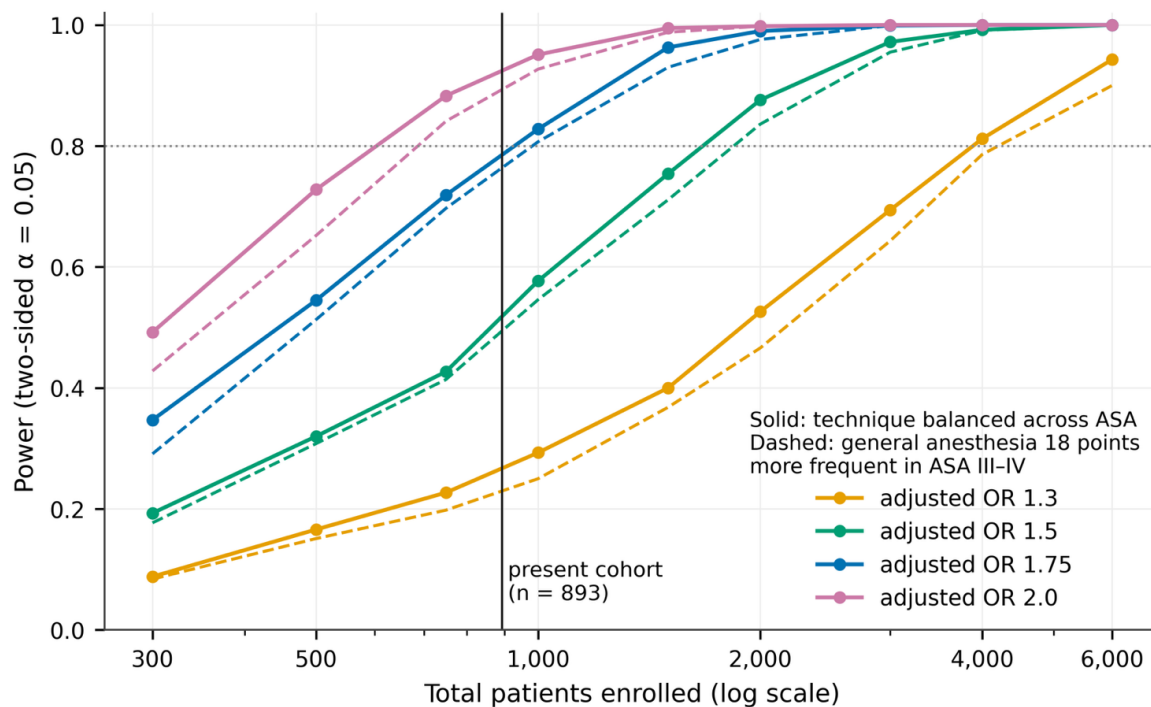


Figure 9. Power to detect an ASA-adjusted odds ratio for general versus regional anesthesia of 1.3–2.0 as a function of total sample size. Solid lines: technique independent of ASA; dashed lines: general anesthesia 18 percentage points more frequent in ASA III–IV than in ASA I–II. The vertical line marks the present cohort.

4. Discussion

In this prospective cohort of 893 older adults undergoing elective non-cardiac surgery in 15 Indonesian tertiary hospitals coordinated from Dr. Saiful Anwar Regional General Hospital, Malang, nearly one in five patients was admitted to the ICU after surgery. ASA physical status showed a steep gradient — from about one in ten ASA II patients to more than four in five ASA IV patients — that persisted in every one of the 4.2 million datasets compatible with the recorded data. Admission was twice as frequent after general as after regional anesthesia; this association withstood every pattern of ASA imbalance short of a 30-point concentration of general anesthesia in sicker patients and every configuration within a clinically plausible region that also allowed comorbidity to vary, but it could not be separated from the surgical procedure, which was not recorded.

The admission rate of 18.8% indicates substantial postoperative critical care use. Descriptive comparison with the Taiwanese, Korean, Irish, Spanish and US cohorts shows wide variation, but their age ranges, procedure mix and admission definitions differ.^{14,18,22,36} The present data

therefore cannot establish whether the Indonesian admission threshold was lower. International and Japanese observational studies have not demonstrated a survival advantage from routine postoperative critical care admission in the populations they examined.¹⁵ Organizational factors may also matter: afternoon scheduling in patients with ASA $\geq$ III was associated with more ICU admissions (adjusted OR 1.40).³⁷ Where step-down units and extended PACU recovery are scarce, the ICU may serve patients who require closer observation than a ward can provide. Without planned versus unplanned admission and organ-support data, this remains a hypothesis.

The ASA gradient agrees in direction with earlier studies. Among older patients undergoing hip-fracture surgery, ICU admission was 15.23% in ASA III–V and 6.18% in ASA I–II patients, a relative risk of 2.46,³⁸ compared with 3.17 in the present cohort. Higher ASA class was associated with unplanned PACU-to-ICU transfer in a large Chinese series³⁹ and with immediate postoperative ICU admission in Taiwan.¹⁸ In the present data, every arrangement of anesthetic technique across ASA classes compatible with the recorded tables gave an adjusted OR of at least 2.84 for ASA III versus II. Adding comorbidity did not reduce the

per-class OR below 2.72 in the configurations explored. Inter-rater variation remains a limitation rather than evidence that the observed gradient is necessarily conservative.^{19,21} A linear model underestimated admission in ASA IV, where 11 of 13 patients were admitted. The two admissions among eight ASA I patients also show that physiological status alone does not determine postoperative ICU use.

As a triage instrument, ASA class is modest. An AUC of 0.679 and a sensitivity of 63.7% for ASA $\geq$ III mean that more than one third of admissions occurred in ASA I–II patients. Assessor variation may contribute: agreement was substantial among anesthesiologists rating standardized cases, poor between internists and anesthesiologists, and fair to moderate in the international MILESTONE-2 survey.^{19,20,21} ASA class also omits surgical magnitude and a direct assessment of frailty. Procedure-specific prediction models,^{22–25} the Preoperative Score to Predict Postoperative Mortality in Thailand,⁴⁰ and frailty studies in Vietnam and China^{8,9} illustrate complementary approaches. In the present cohort an ASA $\geq$ III booking rule would flag about seven patients per hospital per month, of whom two to three were admitted, while one to two admissions arose among unflagged patients. ASA IV, with a positive likelihood ratio of 23.7 and positive predictive value of 84.6%, may assist preoperative ICU planning.

The association of general anesthesia with ICU admission must be interpreted alongside randomized evidence. In REGAIN, death or inability to walk at 60 days occurred in 18.5% after spinal and 18.0% after general anesthesia (relative risk 1.03),²⁸ with no difference in one-year survival.³⁰ In RAGA, delirium occurred in 6.2% after regional and 5.1% after general anesthesia.²⁹ A meta-analysis of randomized trials likewise found no clear delirium advantage.⁴¹ Observational studies reported ICU

admission of 23.8% after general and 6.4% after spinal anesthesia for lower-limb orthopedic surgery²⁶ and more ICU use after general anesthesia in patients with prior stroke.²⁷ Such contrasts may reflect selection of technique. An instrumental-variable analysis of hip-fracture surgery did not associate regional anesthesia with lower 30-day mortality, although length of stay was modestly shorter,⁴² while an Australian and New Zealand registry analysis found that an association with delirium attenuated when hospital preference was used as an instrument.⁴³ These findings support cautious interpretation of observational technique effects.

The present analysis quantifies how much of the technique association could be due to the confounders that were recorded. Adjusting for ASA class could abolish it only if general anesthesia had been given at least 30 percentage points more often to ASA III–IV than to ASA I–II patients; within a plausible imbalance of 20 points, the ASA-adjusted OR remained between 1.82 and 6.74, and with comorbidity also free to vary within plausible limits the lowest value found was 1.34. The association is therefore robust to the recorded case-mix. It is not robust to the case-mix that was not recorded (Figure 10). The E-value of 3.74 means that an unmeasured factor associated with both general anesthesia and ICU admission by a relative risk of 3.74 would explain the crude association entirely. Surgical magnitude is a plausible unmeasured confounder: procedure mix and admission pathways differ across elective surgical cohorts, and 34.6% of patients undergoing elective colorectal surgery in Spain were admitted to critical care.^{14,15} Because the surgical procedure was not recorded, this attribution remains a hypothesis rather than a finding; it would be tested by stratifying the technique association by procedure type in a dataset that records both.

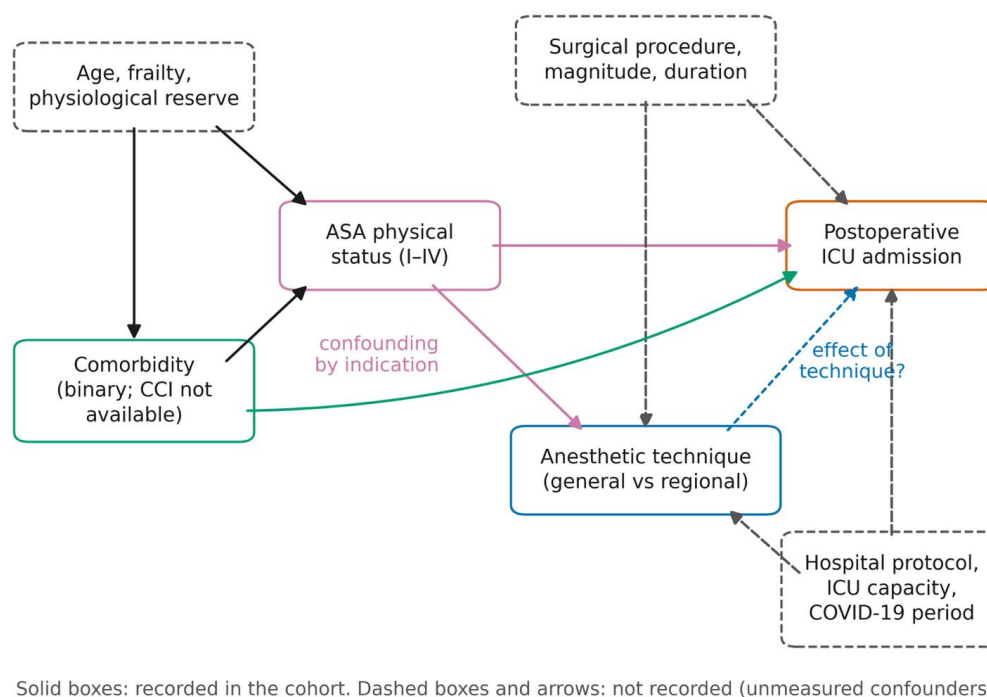


Figure 10. Causal diagram for postoperative ICU admission in older surgical patients. ASA physical status influences both the choice of anesthetic technique and ICU admission (confounding by indication); surgical procedure and hospital capacity, which were not recorded, open further non-causal paths between technique and admission.

A methodological point explains why the ASA-adjusted ORs for technique (median 2.51 under random assignment;

2.57–3.09 when technique was balanced across ASA classes) were close to or above the crude OR of 2.51 in most

admissible tables. The odds ratio is non-collapsible: adjusting for a strong prognostic factor that is unrelated to the exposure moves the conditional OR away from 1 even in the absence of confounding.³⁵ An adjusted OR for technique larger than the crude OR therefore does not indicate that ASA adjustment strengthened the evidence for an effect of anesthesia; it is the expected arithmetic of a strong ASA gradient. Conversely, the narrowest attainable confidence interval for an ASA-adjusted technique OR in these data (standard error of the log-OR 0.218) is wider than that of the crude 2 × 2 table (0.211), as adjustment for a prognostic covariate in logistic regression should produce.

Several physiological pathways link general anesthesia with postoperative deterioration in older patients, and they point to modifiable intraoperative management rather than to the choice of technique as such. Among 48,680 patients aged ≥65 years, mean arterial pressure below 70 mmHg for more than 15 minutes increased major adverse cardiac events (OR 1.51),⁴⁴ and a separate cohort of 33,330 noncardiac operations associated even brief mean arterial pressure below 55 mmHg with acute kidney injury and myocardial injury.⁴⁵ Postoperative pulmonary complications, a common trigger of ICU admission, were reduced from 25.1% to 19.5% by a supraglottic airway in patients aged ≥70 years,⁴⁶ radiographic pneumonia was reduced from 9.6% to 2.4% by sugammadex rather than neostigmine reversal in patients aged ≥75 years in a trial that included Malaysian centers,⁴⁷ and patient-controlled analgesia was associated with fewer unplanned ICU transfers after major abdominal surgery in older patients (1.1% vs 8.4%).⁴⁸ Delirium, which occurred in 12.8% of 5,663 older patients after general anesthesia,⁴⁹ is a further reason for closer postoperative observation. Each of these targets can be addressed within general anesthesia through protocols for blood-pressure thresholds, airway device selection, quantitative monitoring and full reversal of neuromuscular blockade, and multimodal analgesia, and each is within the reach of Indonesian tertiary hospitals.

Comorbidity doubled the crude odds of ICU admission but, unlike ASA class, its adjusted association could not be identified: even within the plausible region its OR ranged from 0.42 to 7.00. This mirrors the literature. A Charlson index above 3 predicted 30-day mortality in the 1,621-patient Indonesian cohort (OR 2.33),³¹ and a Charlson index of 5 or more predicted mortality after hip-fracture surgery in older Brazilian patients,⁵⁰ yet neither the Charlson index nor the five-item modified frailty index predicted critical care admission among older Irish surgical patients,³⁶ and in 1.9 million total knee arthroplasties the Charlson index discriminated mortality less well than the Elixhauser index (AUC 0.74 vs 0.95).⁵¹ A study of BMI and postsurgical outcomes in older adults also emphasizes the need to consider frailty alongside body habitus.⁵² In SNAP-3, multimorbidity increased postoperative morbidity without increasing mortality, while frailty from a Clinical Frailty Scale score of 4 increased both,¹ and a Vietnamese elective gastroenterological cohort associated frailty with adverse postoperative outcomes.⁸ A binary comorbidity indicator, which classifies about 70% of older surgical patients as comorbid, carries little information beyond the ASA class that anesthesiologists already assign.

Sex and BMI deserve brief comment because the recorded data constrain them only weakly. The only reconstruction compatible with the recorded *p* value for sex implies admission of 21.4% of men and 16.4% of women; this is not

an observed result, but a higher risk in men would agree with the higher ASA classes assigned to men independently of comorbidity (adjusted OR 1.24)¹⁷ and with the excess postoperative mortality of men, although that excess diminishes after 65 years of age.⁵³ For BMI, a null linear association (*p*=0.555) does not exclude a U-shaped relation: among 70,487 older Chinese patients, BMI below the optimal range was associated with ICU admission (OR 1.31),⁵⁴ and a separate study of older adults associated extremes of BMI with postsurgical complications while considering frailty.⁵²

The regional and temporal context is important. Data were collected between February and April 2021, when Indonesian ICUs were shared with critically ill COVID-19 patients and when 30-day mortality among older ICU patients in a concurrent national cohort reached 38.6%.³² Indonesian national insurance data documented disruption of hospital use during the pandemic,⁴ and modeling had shown how quickly ICU demand could exceed supply.¹² Two opposite pressures may therefore have acted on the threshold for postoperative admission: scarcity may have reserved ICU beds for the sickest patients, while concern about respiratory deterioration after general anesthesia may have lowered the threshold for observation in a monitored bed. Because COVID-19 status at surgery was not available for analysis, the present admission rate should be read as the rate of a system under strain rather than as a steady-state benchmark. Within Indonesia, general anesthesia was used in 59.8% of 933 older elective patients³³, against 66.3% here, indicating that anesthetic practice varies substantially between hospitals and populations.

These findings have practical implications at the institutional and national levels. First, ASA III–IV status, and ASA IV in particular, should trigger explicit preoperative planning of postoperative care, but ASA class alone should not be used to ration ICU beds, because it misses more than a third of admissions and is applied inconsistently. Second, if many postoperative ICU admissions of older patients are precautionary, investment in intermediate care may release ICU capacity: a surgical high-dependency unit received 38.93% of elective laparoscopic colectomy patients without any requiring vasopressors or ventilation,¹⁶ and unplanned transfer from the PACU to the ICU occurred in only 0.115% of anesthetics in a large Chinese series.³⁹ Third, structured geriatric perioperative care changes both decisions and complications: geriatric co-management reduced incident delirium from 10.0% to 3.3% in older vascular surgical patients;⁵⁵ a randomized trial in older vascular surgical patients found that preoperative comprehensive geriatric assessment and optimization reduced length of stay and several complications;⁵⁶ and comprehensive geriatric assessment of older patients eligible for pancreatic surgery identified 75% as frail and led more of them to non-surgical treatment.⁵⁷ Fourth, the choice between general and regional anesthesia in older patients should continue to follow randomized evidence and surgical requirements rather than expectations about ICU use.

The next study should be designed to close the gaps identified here. Within the existing collaboration, a prospective registry should record, for every patient, ASA class, Clinical Frailty Scale score, Charlson index, surgical specialty and magnitude, duration and blood loss, the exact anesthetic technique, COVID-19 status, whether ICU admission was planned or unplanned, ICU organ support and 30-day outcomes, together with the hospital identifier

and ICU occupancy. The causal question about anesthetic technique is best addressed by emulating a target trial of neuraxial versus general anesthesia in procedures for which both are feasible — lower-limb orthopedic, urological and lower abdominal surgery — with hospital-level preference as an instrumental variable, building on instrumental-variable approaches in hip-fracture surgery.^{43,42} Detecting an adjusted OR of 1.5 with 80% power would require 1,690–1,860 patients (about 320–350 ICU admissions), and an OR of 1.3 would require 3,900–4,250 patients, before inflation for adjustment for surgical magnitude. A definition that records organ support and other ICU-level resources would distinguish necessary from precautionary admissions and allow the planning value of ASA-based booking rules to be evaluated prospectively.

This study has several strengths. It enrolled consecutive older patients prospectively across 15 tertiary hospitals with no missing outcome or predictor data. Every estimate is derived from the recorded tables without imputation, and the multivariable layer, instead of reporting a single model whose specification cannot be verified, reports the complete range of adjusted associations compatible with the data and the narrower range within clinically plausible limits, which makes explicit which conclusions are robust and which are not. Benchmarking against published cohorts places the Indonesian figures in a regional context, and the simulation provides sample sizes for the next study.

The limitations are substantial and specific. The predictors were not cross-classified with one another in the analysis dataset, so adjusted associations are reported as attainable ranges rather than point estimates; analysis of the patient-level REDCap records would allow direct estimation. The surgical procedure, its magnitude and duration were not recorded, and they are the most likely confounders of the technique association. Frailty was not measured, although it is the strongest physiological predictor of adverse outcomes in older surgical patients. Planned and unplanned admissions were not distinguished, ICU admission was a clinical decision subject to local thresholds and pandemic-era capacity, and COVID-19 status, ICU organ support and subsequent outcomes were not available to judge whether admission was necessary. Charlson scores, sex-specific admission counts and BMI values could not be analyzed. ASA class was assigned by attending anesthesiologists without calibration across centers. The number of patients approached and declining consent was not recorded, and the participating hospitals were tertiary referral centers, so the findings may not generalize to district hospitals. Finally, the three-predictor extremes come from a local search and represent lower bounds on the attainable ranges, and the plausible region reflects clinical judgment rather than measured associations.

5. Conclusion

Among 893 older adults undergoing elective non-cardiac surgery in 15 Indonesian tertiary hospitals, 18.8% (95% CI 16.4–21.5) were admitted to the ICU. ASA physical status was robustly associated with admission: the rate rose from 10.4% in ASA II to 84.6% in ASA IV, and the adjusted OR for ASA III versus II was at least 2.84 under every dataset compatible with the recorded data. Admission after general anesthesia was twice that after regional anesthesia (crude OR 2.51, 95% CI 1.66–3.79); the association persists

within plausible case-mix scenarios but cannot be separated from the unrecorded surgical procedure, and randomized evidence does not support a causal effect of technique on outcomes. Indonesian hospitals should use ASA III–IV status to plan postoperative care while recognizing that it misses a third of admissions, and should develop intermediate care and geriatric perioperative services to reserve ICU beds for patients who need organ support. A procedure-level national registry and a target-trial emulation of neuraxial versus general anesthesia, with at least 1,700–1,900 patients, are needed to determine whether anesthetic choice itself alters postoperative ICU use.

6. Declarations

Ethical approval and consent to participate. The study was approved by the CMHC Indonesia Ethics Committee (approval No. 2024/8442). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from every participant or a legally authorized representative at enrollment.

Consent for publication. No individually identifiable participant data are presented in this manuscript.

Availability of data and materials. De-identified patient-level data are available from the corresponding author on reasonable request.

Artificial intelligence (AI) use statement. None declared.

Author contribution statement. AIZ: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. II: Conceptualization, Supervision, Validation, Writing – review and editing. TAS: Investigation, Data curation, Writing – review and editing. BHL: Supervision, Resources, Writing – review and editing.

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