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Impact of cardiac surgery and neurosurgery patients on variation in severity-adjusted resource use in intensive care units

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ABSTRACT

Purpose: The resource use of cardiac surgery and neurosurgery patients likely differ from other ICU patients. We evaluated the relevance of these patient groups on overall ICU resource use.

Methods: Secondary analysis of 69,862 patients in 17 ICUs in Finland, Estonia, and Switzerland in 2015–2017. Direct costs of care were allocated to patients using daily Therapeutic Intervention Scoring System (TISS) scores and ICU length of stay (LOS). The ratios of observed to severity-adjusted expected resource use (standardized resource use ratios; SRURs), direct costs and outcomes were assessed before and after excluding cardiac surgery or cardiac and neurosurgery.

Results: Cardiac surgery and neurosurgery, performed only in university hospitals, represented 22% of all ICU admissions and 15–19% of direct costs. Cardiac surgery and neurosurgery were excluded with no consistent effect on SRURs in the whole cohort, regardless of cost separation method. Excluding cardiac surgery or cardiac surgery plus neurosurgery had highly variable effects on SRURs of individual university ICUs, whereas the non-university ICU SRURs decreased.

Conclusions: Cardiac and neurosurgery have major effects on the cost structure of multidisciplinary ICUs. Extending SRUR analysis to patient subpopulations facilitates comparison of resource use between ICUs and may help to optimize resource allocation.

1. Introduction

Intensive care requires extensive resources to prevent death and disability in acutely ill patients and after major, complex surgery [1-3]. Evolution of resources needed for the care of intensive care unit (ICU) patients and assessing ICU performance in saving lives is of major interest because of the high mortality of ICU patients and the high costs of ICU care. We recently demonstrated a substantially decreased severity of illness-adjusted hospital mortality (standardized mortality ratio; SMR) over time in ICU patients without an increase in severity-adjusted resource use ratio (SRUR), and a wide and independent variation in both mortality and resource use between ICUs [4].

Patients undergoing cardiac surgery or intracranial neurosurgery are typically treated in the ICU postoperatively, and their care is often concentrated in tertiary care hospitals. In our study on variation of resource utilization and outcome, cardiac surgery represented 13% and intracranial neurosurgery and head trauma 9% of ca 70,000 admissions in 17 ICUs in Finland, Estonia and Switzerland in 2015–2017 [4]. The pattern of resource utilization and outcome in these two distinct groups of ICU patients is likely to differ from the rest of the general ICU population. The majority of these patients are admitted after elective surgery. Most cardiac surgery patients need a brief but intensive treatment and mortality is low in this patient group. Many neurosurgical patients are admitted for observation with a low intensity of treatment, whereas the assessment of severity of illness in head trauma may be confounded by sedation. The impact of cardiac surgery, neurosurgery, or both on SRUR of ICUs is unknown.

We previously observed that SRURs and SMR all had an interaction between ICU category and severity of illness. In addition, the category

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small non-university ICU was associated with increased SMR and the university ICUs had higher ranges of SRURs and lower ranges of SMRs than the non-university ICUs [4]. We hypothesized that treatment of cardiac surgery and neurosurgery patients in university ICUs may contribute to this. Understanding the impact of these major patient groups on the overall costs of ICU care and SRUR will facilitate comparison of resource use between ICUs and may help to optimize resource allocation.

We therefore evaluated the relevance and contribution of cardiac surgery and intracranial neurosurgery and head trauma to the costs of care and SRUR of multidisciplinary ICUs, by separating the costs of care of these patient groups from the costs of general ICU patients.

2. Material and methods

This is a preplanned secondary analysis of the study on variation in severity-adjusted resource use and outcome in intensive care units in Finland, Estonia, and Switzerland [4]. The data was extracted into an anonymized database from a benchmarking database. The protocol, database contents and data management process of the main study were approved by the National Institute of Health and Welfare, Finland (Decision THL/1524/5.05.00/2017 and THL/1173/05.00/2018) and registered as ISRCTN12457206. According to regulations in Finland, Estonia, and Switzerland, no ethics committee approval was needed. Resource use, direct cost and outcome data for all admissions (n = 69,862) in 17 of 21 ICUs in 2015–2017 (8 university, 4 large non-

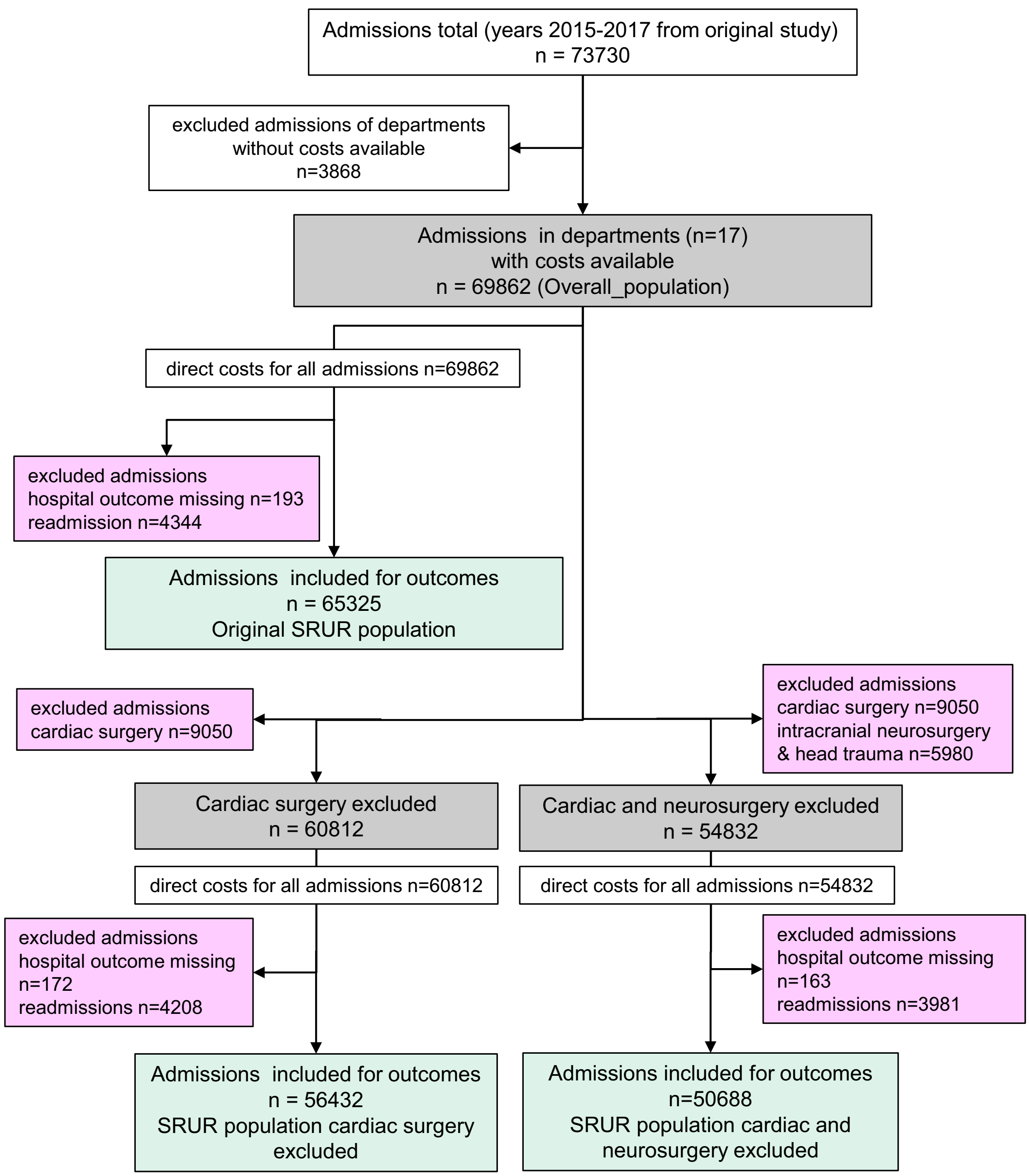


Fig. 1. Flow chart showing study populations and exclusions.

university, 5 small non-university ICUs; criteria in Supplementary information; SI) from the original study were included in the present study. Admissions of 4 departments without direct cost data were excluded ($n = 3868$). All ICUs were general mixed ICUs; one university hospital had a geographically separate subunit for cardiac surgery patients.

2.1. Study populations

The *Overall* population (Fig. 1) included all admissions and resources used by the 17 ICUs; this is equal to the cost population of the original study [4].

The *Cardiac surgery excluded* population included all except admissions due to cardiac surgery. The *Cardiac and neurosurgery excluded* population included all except admissions due to cardiac surgery, intracranial neurosurgery and head trauma. For hospital survivor count, readmissions and admissions missing hospital outcome were excluded (*SRUR population cardiac surgery excluded*, *SRUR population cardiac and neurosurgery excluded*).

2.2. Resource use

We assessed resource use using ICU length of stay (LOS), daily collected Therapeutic Intervention Scoring System-76 (TISS) scores [5] including 17 additional items (SI, referred throughout using prefix "e": eTable1), and direct ICU costs (salaries, drugs, fluids, disposables) as previously described [4].

2.3. Separation of costs of cardiac and neurosurgery

We calculated the proportion of resources used for these two subpopulations as their proportion of total LOS and total TISS and the respective proportions of total direct costs. Because the proportions of subpopulation LOS and TISS of total direct costs may not be identical, all cost calculations were done using both proportions.

2.4. Calculation of SRUR

Calculation of SRUR has been described in detail including a practical example [4]. Briefly, all yearly ICU admissions were stratified according to Simplified Acute Physiology Score II (SAPS II) [6] scores (0–9, 10–19, …, 80–89, >90). First, in each stratum, the sums of all LOS days and TISS scores of both hospital survivors and non-survivors (populations *Cardiac surgery excluded*, *Cardiac and neurosurgery excluded*) divided by the number of hospital survivors (*SRUR population cardiac surgery excluded*, *SRUR population cardiac and neurosurgery excluded)* in that stratum indicated the *expected LOS/survivor and TISS)/survivor*. Second, for each ICU, the *expected LOS/survivor and TISS)/survivor* were multiplied by the number of survivors in each SAPS-II stratum and the expected LOS and TISS for the ICU was their sum in all SAPS-II strata. The mean costs of one ICU LOS day and TISS point for each subpopulation were calculated as the subpopulation direct costs divided by the respective sum of LOS days and TISS points. For each ICU, the expected direct costs were obtained by multiplying the expected total LOS and TISS by the mean cost of LOS and TISS. The cost-based SRURs for each ICU was calculated as observed/expected total direct costs based on LOS ($SRUR_{LOS}$) and TISS ($SRUR_{TISS}$).

We used a fixed exchange rate of 1.09 Swiss franc to 1.00 Euro, without inflation adjustment, and we adjusted the costs for purchasing power parity [4,7].

2.5. Statistical analysis

We followed a similar analysis strategy as previously described [4]. We described the study population by frequencies (n), percentages (%), means, standard deviations (SD), median and percentiles. Differences across ICU categories were tested by an analysis of variance and a chi-squared test. We used box plots to describe SRUR by calendar year. We used Gamma distributed hierarchical regression models with clusters on hospitals to investigate ICU-related factors associated with $costSRUR_{LOS}$ and $costSRUR_{TISS}$. The following ICU-related variables were included: ICU-category (university, small/large non-university), median SAPS-II and SMR based on a customized model [8]. We used bivariable models (one of the above variables adjusted for calendar year) and multivariable models (all of the above variables adjusted for calendar year). Continuous variables were standardized (centered and expressed per one standard deviation increase) and relative risk estimates (RR) reported with 95% confidence intervals. All analyses were performed in R version 4.1.2 (R Team Core. R: A language and environment for statistical computing, Vienna, Austria. R Foundation for Statistical Computing).

3. Results

3.1. ICU and admission characteristics

Direct costs were available for 17 ICUs (8 university, 4 large non-university, 5 small non-university ICUs; main characteristics of the ICUs in eTable 2). The admissions of these ICUs represented 94.7% of all admissions in the original study in 2015–2017. The admission characteristics across ICU categories were different (Table 1; all p-values <0.001, except $p = 0.006$ for LOS). The non-university ICUs had mostly emergency (>90%) and non-surgical admissions (>70%) with higher median SAPS- II as compared to the university ICUs with more elective (34%) and surgical admissions (53%) and short median LOS. The university hospitals provided 82% of all ICU admissions, and the two university hospital ICUs in Estonia and Switzerland 34% of all university hospital admissions. The cardiac surgery and neurosurgery admissions were almost explicitly in the university hospital ICUs (>99%) and contributed, respectively, to 13% and 9% or a total of 22% of all admissions (Table 1, Table 2, eTable 3). The cardiac surgery and neurosurgery admissions had lower median SAPS-II scores, and lower mean TISS score sum and length of stay as compared to the remaining population (Table 2). Four university ICUs treated admissions from both in-house cardiac and neurosurgery services, one from an in-house cardiac surgery service, and two from an in-house neurosurgery service. Two ICUs discharged cardiac surgery patients routinely directly to normal ward, two ICUs all and one ICU ca. 30–50% of cardiac surgery patients to a separate intermediate care unit.

3.2. Analysis of direct costs - impact of using LOS or TISS for cost separation

In the overall population in 2015–2017, the direct costs for cardiac surgery admissions of total direct costs were 7–9% (LOS-based) and 10–12% (TISS-based), and those of cardiac and neurosurgery admissions 15–16% (LOS-based) and 17–19% (TISS-based; eTable 4). The direct costs per ICU admission were 2%–6% higher and those per survivor 4%–8% higher after exclusion of cardiac surgery patient (Table 3). After further exclusion of neurosurgery admissions, the costs for the remaining admissions were 4%–8% higher per ICU admission and 8%–12%, higher per survivor by as compared to respective costs of all admissions. The increase in costs of TISS-score were smaller (0%–4%) and the costs of ICU-day decreased slightly (0%–4%). The exclusion-induced directional changes in costs were independent on the cost separation method, but the TISS-based approach resulted consistently in smaller increases and larger decreases (Table 3).

3.3. Effects of excluding subpopulations on $SRUR_{LOS}$ and $SRUR_{TISS}$

The results using TISS-based cost separation are presented here and the LOS-based cost separation in eFigure 1.

Excluding cardiac surgery or cardiac surgery and neurosurgery had no consistent effect on $SRUR_{LOS}$ and $SRUR_{TISS}$ in the whole cohorts, regardless of cost separation method (Fig. 2, eFigure 1). In contrast, there were relevant changes at the level of individual ICUs. The SRURs

Table 1
Admission characteristics by intensive care unit category and overall.

	University ($N = 56{,}949$)	Non-university (large) ($N = 7688$)	Non-university (small) ($N = 5225$)	Overall ($N = 69{,}862$)
Age (years)				
Mean (SD)	60.2 (17.5)	57.7 (19.9)	62.9 (17.7)	60.2 (17.8)
Median [Min, Max]	64.0 [0,100]	63.0 [0, 98.0]	66.0 [0, 100]	64.0 [0, 100]
Gender				
Male	35,459 (62.3%)	4622 (60.1%)	3349 (64.1%)	43,430 (62.2%)
Female	21,480 (37.7%)	3066 (39.9%)	1876 (35.9%)	26,422 (37.8%)
Missing	10 (0.0%)	0 (0%)	0 (0%	10 (0.0%)
Type of admission				
Readmission	3563 (6.3%)	537 (7.0%)	264 (5.1%)	4364 (6.2%)
First admission	53,386 (93.7%)	7151 (93.0%)	4961 (94.9%)	65,498 (93.8%)
Treatment type				
Elective	19,788 (34.7%)	265 (3.4%)	420 (8.0%)	20,473 (29.3%)
Emergency	37,161 (65.3%)	7423 (96.6%)	4805 (92.0%)	49,389 (70.7%)
Surgical treatment				
Non-surgical	26,845 (47.1%)	6230 (81.0%)	3785 (72.4%)	36,860 (52.8%)
Surgical	30,104 (52.9%)	1458 (19.0%)	1440 (27.6%)	33,002 (47.2%)
SAPS-II score stratum				
0–9	2584 (4.5%)	188 (2.4%)	62 (1.2%)	2834 (4.1%)
10–19	9315 (16.4%)	1015 (13.2%)	556 (10.6%)	10,886 (15.6%)
20–29	16,476 (28.9%)	2012 (26.2%)	1305 (25.0%)	19,793 (28.3%)
30–39	12,174 (21.4%)	1855 (24.1%)	1273 (24.4%)	15,302 (21.9%)
40–49	7076 (12.4%)	1239 (16.1%)	887 (17.0%)	9202 (13.2%)
50–59	4471 (7.9%)	654 (8.5%)	531 (10.2%)	5656 (8.1%)
60–69	2744 (4.8%)	386 (5.0%)	324 (6.2%)	3454 (4.9%)
70–79	1256 (2.2%)	172 (2.2%)	166 (3.2%)	1594 (2.3%)
80–89	528 (0.9%)	95 (1.2%)	63 (1.2%)	686 (1.0%)
90-	325 (0.6%)	72 (0.9%)	58 (1.1%)	455 (0.7%)
SAPS-II score				
Mean (SD)	33.0 (17.1)	35.3 (17.2)	37.6 (17.3)	33.6 (17.2)
Median [Min, Max]	30.0 [0,122]	33.0 [0,111]	34.0 [2.00, 135]	30.0 [0, 135]
TISS EXT score sum				
Mean (SD)	123 (209)	107 (167)	121 (145)	121 (200)
Median [Min, Max]	63.0 [1.00, 5830]	57.0 [2.00, 3520]	76.0 [6.00, 2220]	63.0 [1.00, 5830]
Missing	31 (0.1%)	3 (0.0%)	2 (0.0%)	36 (0.1%)
Length of stay (days)				
Mean (SD)	2.94 (5.17)	3.05 (5.13)	3.14 (4.16)	2.97 (5.10)
Median [Min, Max]	1.09 [0.000694, 136]	1.54 [0.00139, 118]	1.87 [0.00694, 59.9]	1.16 [0.000694, 136]
Outcome in hospital				
Survivor	51,693 (90.8%)	6777 (88.2%)	4380 (83.8%)	62,850 (90.0%)
Non-survivor	5256 (9.2%)	911 (11.8%)	845 (16.2%)	7012 (10.0%)

Abbreviations: SAPS-II = simplified acute physiology score; LOS = length of stay in the intensive care unit; TISS = Therapeutic intervention scoring system; TISS EXT score sum includes the additional items described in the Methods and Supporting Information.
The admission characteristics across ICU categories were different: all p-values <0.001, except $p = 0.006$ for LOS.

decreased for all ICUs without in-house cardiac or neurosurgery service, i.e., the non-university ICUs and one university ICU. The responses of the ICUs with either cardiac or neurosurgery service or both was much more variable, ranging from slight decreases to major increases in individual ICUs (Fig. 3).

No significant association between ICU category, SAPS-II and SMR with SRURs was observed (Fig. 4, eFigure 2).

3.4. Impact on ranking ICUs according to the SRURs

When the ICUs were ranked according to increasing SRURs in the overall population, the rank order for all units was the same with $SRUR_{LOS}$ and $SRUR_{TISS}$ (eFigure 3). After exclusion of cardiac surgery or cardiac and neurosurgery, the maximum change in rank from the original was ±2 in 2015–2016 and ± 3 in 2017 (rank increase indicating higher SRUR). ICUs within ranks 1–5 ("high performers"), ranks 6–11 ("middle performers"), and 12–17 ("Low performers") remained the same with both TISS- and LOS-based cost separation, except in 2017, when three units switched between "high" and "middle performers" in $SRUR_{TISS}$-rankings (ranks 3–6).

4. Discussion

We provide new information on the relevance and contribution of cardiac surgery and intracranial neurosurgery and head trauma on the costs of care and SRUR in multidisciplinary ICUs. As expected, these two distinct ICU-patient groups differed from the general ICU-patient population: cardiac surgery and neurosurgery admissions were performed explicitly in university hospital, the majority were postoperative admissions after elective surgery, and the mortality was lower. The main findings were:

1. Excluding cardiac surgery and neurosurgery or cardiac surgery had no consistent effect on $SRUR_{LOS}$ and $SRUR_{TISS}$ in the whole cohort, regardless of cost separation method.
2. Excluding cardiac surgery and neurosurgery or cardiac surgery decreased the SRURs of the non-university ICUs, whereas the impact on individual university ICUs was highly variable.
3. The contribution of cardiac surgery and neurosurgery admissions to total admissions was higher than their share of total direct costs.

These observations indicate that intensive care for cardiac and neurosurgery has a major effect on the cost structure of multidisciplinary ICUs, and should be considered in the assessment of resource utilization. We used a novel approach of SRUR analysis to evaluate effects of patient subpopulations on the SRURs. The same methodology can be applied to any subpopulation to assess the impact of actual or potential differences in the case mix on resource utilization, as long as the total resource use (as costs or other indicators) and the patient level resource use (e.g. LOS or TISS) is known. The main features of this new approach need to be

Table 2
Admission characteristics by exclusions.

	Without cardiac surgery ($N = 60{,}812$)	Excluded cardiac surgery admissions ($N = 9050$)	Without cardiac and neurosurgery ($N = 54{,}832$)	Excluded cardiac and neurosurgery admissions ($N = 15{,}030$)
Age (years)				
Mean (SD)	59.2 (18.4)	66.3 (11.2)	59.4 (18.5)	62.9 (14.9)
Median [Min, Max]	63.0 [0, 100]	68.0 [16.0, 93.0]	63.0 [0, 100]	66.0 [0, 97.0]
Gender				
Male	36,648 (60.3%)	6782 (74.9%)	33,443 (61.0%)	9987 (66.4%)
Female	24,154 (39.7%)	2268 (25.1%)	21,379 (39.0%)	5043 (33.6%)
Missing	10 (0.0%)	0 (0%)	10 (0.0%)	0 (0%)
Type of admission				
Readmission	4227 (7.0%)	137 (1.5%)	4000 (7.3%)	364 (2.4%)
First admission	56,585 (93.0%)	8913 (98.5%)	50,832 (92.7%)	14,666 (97.6%)
Treatment type				
Elective	12,353 (20.3%)	8120 (89.7%)	9081 (16.6%)	11,392 (75.8%)
Emergency	48,459 (79.7%)	930 (10.3%)	45,751 (83.4%)	3638 (24.2%)
Surgical treatment				
Non-surgical	36,860 (60.6%)	0 (0%)	36,860 (67.2%)	0 (0%)
Surgical	23,952 (39.4%)	9050 (100%)	17,972 (32.8%)	15,030 (100%)
SAPS-II score stratum				
0–9	2672 (4.4%)	162 (1.8%)	1886 (3.4%)	948 (6.3%)
10–19	9191 (15.1%)	1695 (18.7%)	7654 (14.0%)	3232 (21.5%)
20–29	15,729 (25.9%)	4064 (44.9%)	14,292 (26.1%)	5501 (36.6%)
30–39	13,164 (21.6%)	2138 (23.6%)	12,272 (22.4%)	3030 (20.2%)
40–49	8600 (14.1%)	602 (6.7%)	8047 (14.7%)	1155 (7.7%)
50–59	5407 (8.9%)	249 (2.8%)	4993 (9.1%)	663 (4.4%)
60–69	3359 (5.5%)	95 (1.0%)	3084 (5.6%)	370 (2.5%)
70–79	1568 (2.6%)	26 (0.3%)	1503 (2.7%)	91 (0.6%)
80–89	675 (1.1%)	11 (0.1%)	659 (1.2%)	27 (0.2%)
90-	447 (0.7%)	8 (0.1%)	442 (0.8%)	13 (0.1%)
SAPS-II score				
Mean (SD)	34.5 (17.7)	27.6 (10.8)	35.2 (17.7)	27.6 (13.6)
Median [Min, Max]	31.0 [0, 135]	26.0 [0, 109]	32.0 [0, 135]	26.0 [0, 109]
TISS EXT score sum				
Mean (SD)	123 (209)	106 (132)	126 (213)	104 (147)
Median [Min, Max]	57.0 [1.00, 5830]	78.0 [8.00, 4420]	60.0 [1.00, 5830]	71.0 [8.00, 4420]
Missing	35 (0.1%)	1 (0.0%)	33 (0.1%)	3 (0.0%)
Length of stay (days)				
Mean (SD)	3.16 (5.35)	1.66 (2.53)	3.21 (5.43)	2.07 (3.47)
Median [Min, Max]	1.41 [0.000694, 136]	0.948 [0.0535, 46.1]	1.52 [0.000694, 136]	0.954 [0.0507, 89.6]
Outcome in hospital				
Survivor	53,967 (88.7%)	8883 (98.2%)	48,283 (88.1%)	14,567 (96.9%)
Non-survivor	6845 (11.3%)	167 (1.8%)	6549 (11.9%)	463 (3.1%)

Abbreviations: SAPS-II = simplified acute physiology score; LOS = length of stay in the intensive care unit; TISS = Therapeutic intervention scoring system; TISS EXT score sum includes the additional items described in the Methods and Supporting Information.

addressed to facilitate critical interpretation of our results. The SRUR of an individual ICU is the ratio of observed to expected resources used to produce survivors. When a subpopulation is excluded, its share of the costs in each ICU is subtracted from the ICU total costs. This cost separation can be done using the subpopulation proportion of either TISS or LOS. This will reduce the total costs, TISS and LOS of the remaining population, usually in different proportions.The remaining costs, TISS and LOS are used to recalculate the observed and expected costs for the remaining population. Therefore, the separation of a subpopulation will influence the mean costs of TISS and LOS, and the observed and expected costs for the severity strata. This is illustrated for 2017 and as an example for one ICU in Fig. 5.The net effect on SRURs will depend on the relative changes in each of these variables and will also impact ICUs without admissions in the subpopulation.

Table 3
DIRECT COSTS AND EXCLUSION OF CARDIAC AND NEUROSURGERY ADMISSIONS: LOS- and TISS-based separation of total direct costs.

Direct costs (Euro) per		All admissions	Admissions excluded from cost calculations			
			Cardiac surgery		Cardiac and neurosurgery	
	Year	Total direct costs	LOS-based direct costs	TISS-based direct costs	LOS-based direct costs	TISS-based direct costs
ICU admission	2015	6109	6459	6211	6575	6354
	2016	6295	6677	6436	6804	6588
	2017	6286	6649	6409	6810	6588
ICU day	2015	2082	2067	1987	2075	2005
	2016	2097	2086	2011	2094	2028
	2017	2125	2112	2036	2120	2051
TISS score	2015	51	53	51	53	52
	2016	52	54	52	54	52
	2017	51	53	51	53	51
Survivor	2015	7183	7763	7464	8002	7733
	2016	7500	8127	7834	8382	8116
	2017	7467	8070	7779	8349	8077

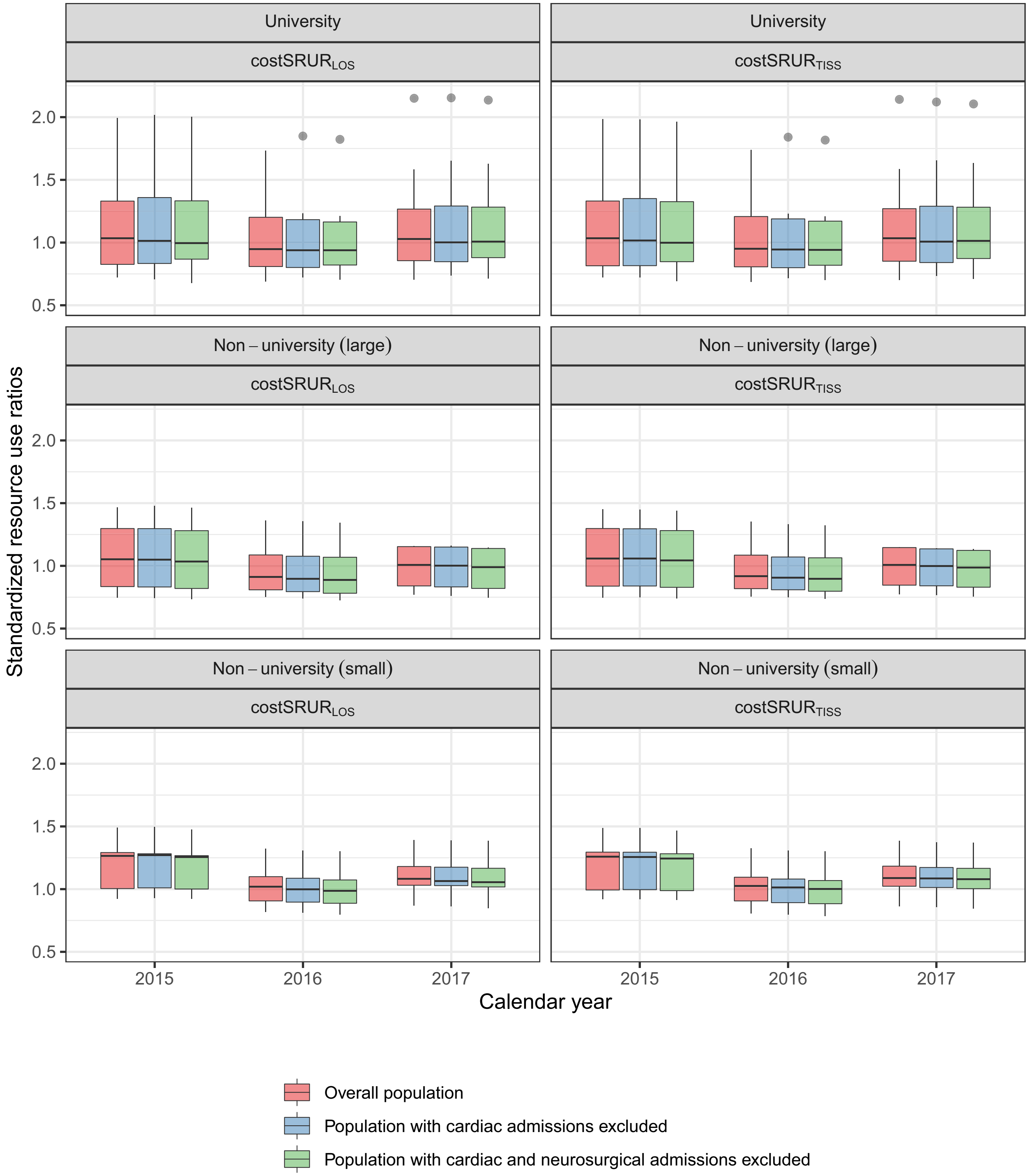


Fig. 2. Effect of excluding cardiac surgery admissions (left panel) and both cardiac and neurosurgery admissions (right panel) on standardized resource utilization ratios ($SRUR_{LOS}$ and $SRUR_{TISS}$) in university and non-university ICUs.; box plots show the median, the first and third quartiles, and whiskers defined by 1.5 times the interquartile range. Cost separation based on TISS. For cost separation based on LOS, see eFigure 1.

Costs per survivor increase with increasing severity of illness (Fig. 5), and accordingly, costs per ICU day and per survivor will be influenced by the case mix. The cardiac surgery and neurosurgery admissions were less severely ill, had lower mean TISS score sum, shorter mean length of stay and lower mortality as compared to other patients. This means that cost per ICU day and per survivor were lower for cardiac surgery and neurosurgery patients than for other patients, and consequently, exclusion of these two subpopulations and resources used for them

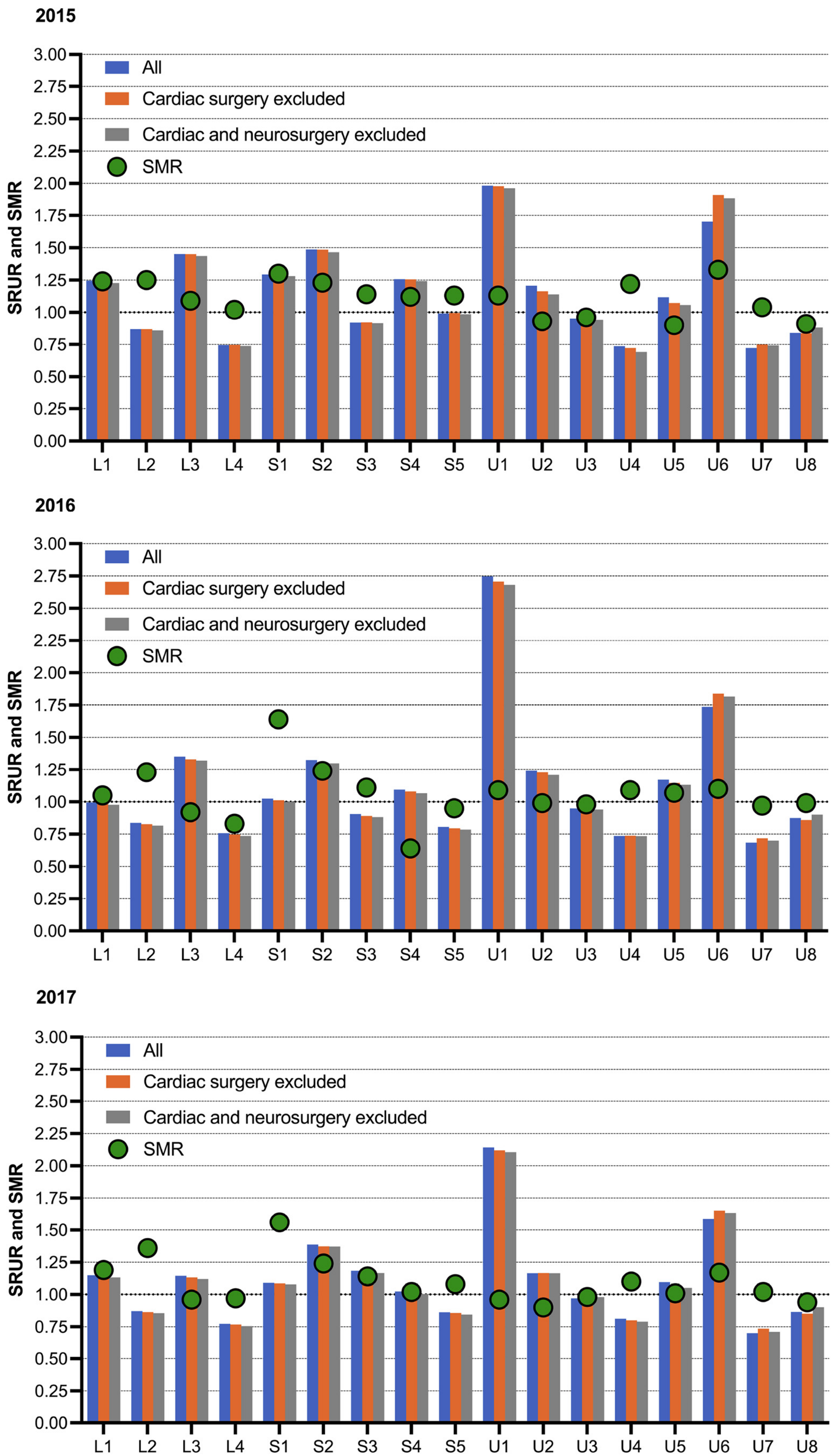


Fig. 3. $SRUR_{TISS}$ and SMR of individual ICUs. Effect of exclusion of cardiac surgery and cardiac and neurosurgery admissions on $SRUR_{TISS}$ (L1-L5: large non-university hospital ICUs; S1-S4: small non-university hospital ICUs; U1-U8: university hospital ICUs). Cost separation based on TISS. Cost separation based on TISS for $SRUR_{LOS}$ in eFigure 4; SRURs with cost separation based on LOS in eFigure 5–6.

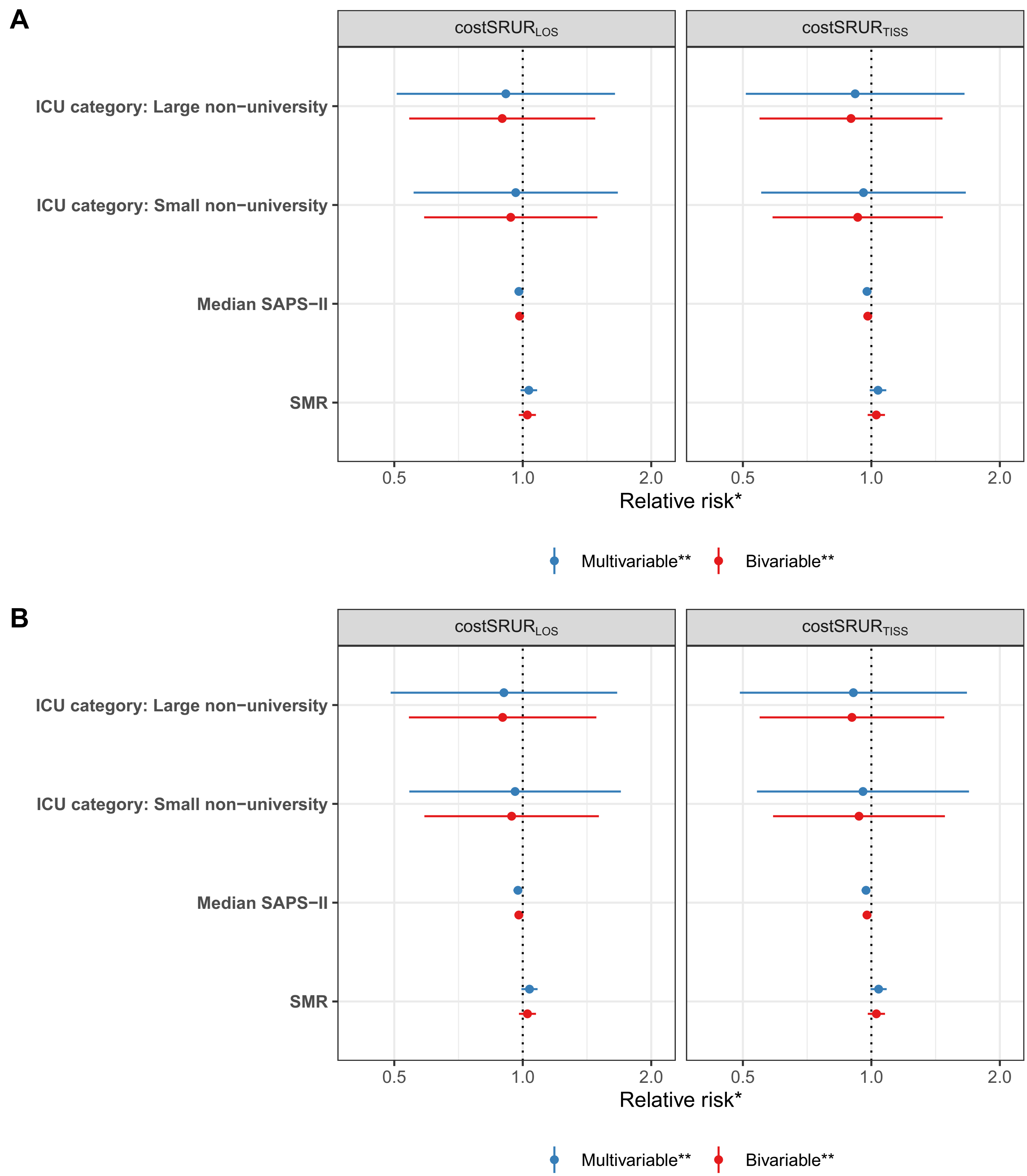
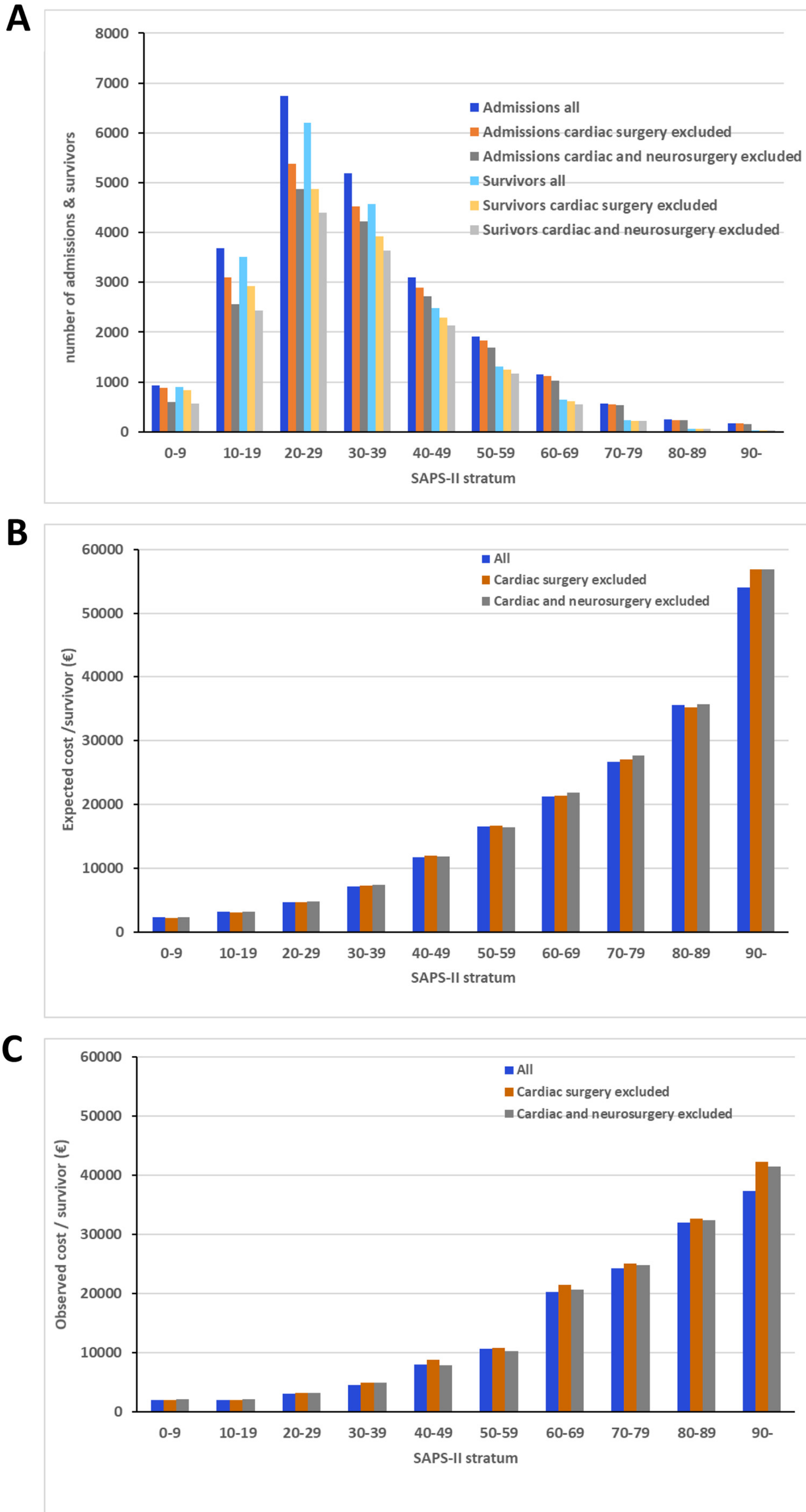


Fig. 4. Bivariable and multivariable analyses of associations between standardized resource utilization ratios ($SRUR_{LOS}$, $SRUR_{TISS}$), ICU category, median SAPS II score and standardized mortality ratio (SMR).
Panel A: cardiac surgery admissions excluded.
Panel B: both cardiac and neurosurgery admissions excluded.
*Relative risk with 95% confidence intervals. Values>1 indicate higher SRUR. The relative risk of 1.0 (dotted line) indicates an SRUR of 1. **reported variables adjusted for calendar year (bivariable), and in addition for all other listed variables (multivariable).
Cost separation based on TISS. For cost separation based on LOS, see eFigure2.


A
number of admissions & survivors
Admissions all
Admissions cardiac surgery excluded
Admissions cardiac and neurosurgery excluded
Survivors all
Survivors cardiac surgery excluded
Surivors cardiac and neurosurgery excluded
SAPS-II stratum
B
Expected cost /survivor (€)
All
Cardiac surgery excluded
Cardiac and neurosurgery excluded
SAPS-II stratum
C
Observed cost / survivor (€)
All
Cardiac surgery excluded
Cardiac and neurosurgery excluded
SAPS-II stratum

therefore results in higher mean cost per ICU day and per survivor. The SRURs take the case mix effect into account by allocating the resource use to severity of illness data and adjusting the expected costs for severity of illness.

The separation of subpopulation costs based on TISS vs. LOS resulted in consistent directional changes in SRURs. The tendency of larger decreases in SRURs after TISS-based exclusion may reflect the differences between TISS and LOS as surrogate indicators of resource use. It is also plausible that short ICU stays with high TISS in the excluded population (Table 2) could contribute.

The exclusion of cardiac surgery and neurosurgery patients was bound to have the main impact on the university ICUs providing these services. The small consistent decrease in the non-university ICU SRURs reflects the on average higher expected cost of survivors (Table 3, Fig. 5). Accordingly, the presence of low-risk patients in a subgroup of ICUs of a benchmark cohort artificially decreases the perceived performance of the rest of the ICUs. This should be acknowledged.

The wide variation between individual university ICUs in response to exclusion of cardiac surgery and neurosurgery suggests major differences between the units in the costs of care of the general ICU population, which may be further amplified by differences in SMR. We reported earlier large differences in the direct costs and their structure between the units when all admissions were included [4]. The present observations suggests that this pattern may even be amplified, when cardiac and neurosurgery patients are excluded.

The results further confirm the robustness of the SRUR concept in evaluation of ICU resource use and extends it to the evaluation of ICU subpopulations. The choice of cost separation (TISS- or LOS-based) of cost indicator (TISS or LOS) has no relevant impact on the main results. We believe that using both cost separation approaches and both cost indicators may provide additional insight to the causes of SRUR variation.

Cost finding and allocation, and the variation in case-mix and severity-adjusted outcomes between ICUs are well-recognized problems in the evaluation of ICU resource use [1-4,9-16]. Statistical models based on weighted hospital day costs [1,12], weighted LOS, combined with severity of illness indicators, outcome, and charge-derived costs [13,15] have been used to compare the clinical and economic performance between ICUs. These approaches are likely insensitive to major differences between specific patient groups in their pattern of resource use intensity during the ICU-stay. The "bottom-up" costing of some components of costs of individual patients has been done, but it is not feasible in large cohorts [10,16-19]. Previous data on the contribution of subgroups to overall resource use in the general ICU population are scarce. In an observational multicenter study in 54 Italian ICUs, variable costs per patient were related to diagnosis (e.g. much higher in trauma than in scheduled surgery patients) and mortality [18]. Comparison of ICUs was not possible since data of only 5–10 admissions from each ICU were considered. No cardiac surgery patients were included. Recently, a prediction model for postoperative use of ICU resources was published [20]. The study did not include costs of cardiac surgery. The use of TISS and LOS to allocate resource use per patient provides complementary information. Costs per ICU-day may vary widely depending on the underlying disease and the phase of ICU-stay. In contrast, TISS is related to specific interventions and care activities, and is thus independent of the diagnosis. The main potential limitation of TISS-scores is the relative weight assigned to each TISS-item. Nevertheless, our results using TISS and LOS were very similar and support the robustness of our approach.

The strengths of our study include, ICUs with direct costs available representing almost 95% of all eligible admissions, and cost data adjusted for PPP from three different health care systems and wealth, standardized and validated data acquisition, clear allocation of direct costs, and a large database with very few missing data for resource use allocation for each admission. The limitations include the mix of ICUs: only university ICUs outside of Finland were included, and they represented 33% and100% of university ICU admissions in Switzerland and Estonia, respectively. Cost structures in other ICUs in these countries may be different. There may have been small inaccuracies in allocation of physician salary costs, as addressed previously [4], but their proportion of total direct costs is small. We did not evaluate the impact of neurosurgical patients without actual surgery, e.g. subarachnoidal hemorrhage with endovascular treatment or nonsurgical intracerebral bleedings; their contritubution should be studied separately. Our study does not address resource use outside the ICU. It is clear that large differences in such costs exist (e.g. in the operation room) and they have no direct relationship with the ICU resource use. The results of surgical patients may not be generalizable to other European countries, since surgical mortality rates in Finland, Switzerland and Estonia are among the lowest in Europe [21]. Our results demonstrate the consistency of SRURs independent of the method of cost separation. This strongly suggest that the effects of specific patient groups on the SRURs can reliably be done, when patient-level indicators of resource use, such as LOS or TISS, are available. This may facilitate the future evaluation of effects of any specific patient group on the severity-adjusted resource use of intensive care.

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CRediT authorship contribution statement

Jukka Takala: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft, Visualization, Supervision, Project administration. **André Moser:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – review & editing, Visualization. **Matti Reinikainen:** Conceptualization, Methodology, Writing – review & editing. **Tero Varpula:** Conceptualization, Methodology, Writing – review & editing. **Rahul Raj:** Investigation, Resources, Data curation, Writing – review & editing, Supervision, Project administration. **Stephan M. Jakob:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision.

Declaration of Competing Interest

On behalf of all authors, the corresponding author states that there are no conflicts of interests.

Fig. 5. Effect of exclusion of cardiac surgery admissions and cardiac and neurosurgery admissions on components of SRUR in 2017: TISS-based cost separation.
Panel A: number of admissions and survivors.
Panel B: expected TISS-based cost/survivor at each SAPS-stratum.
Panel C: example of observed costs/survivor in one university ICU (U7) with both cardiac and neurosurgery admissions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2022.154110.

References

[1] Halpern NA, Pastores SM. Critical care medicine in the United States 2000-2005: an analysis of bed numbers, occupancy rates, payer mix, and costs. Crit Care Med. 2010; 38:65–71. https://doi.org/10.1097/CCM.0b013e3181b090d0.

[2] Tan SS, Bakker J, Hoogendoorn ME, Kapila A, Martin J, Pezzi A, et al. Direct cost analysis of intensive care unit stay in four European countries: applying a standardized costing methodology. Value Health. 2012;15:81–6. https://doi.org/10.1016/j.jval.2011.09.007.

[3] Lindemark F, Haaland ØA, Kvaele R, Flaatten H, Norheim OF, Johansson KA. Costs and expected gain in lifetime health from intensive care versus general ward care of 30,712 individual patients: a distribution-weighted cost-effectiveness analysis. Crit Care. 2017;21:220. https://doi.org/10.1186/s13054-017-1792-0.

[4] Takala J, Moser A, Raj R, Pettilä V, Irincheeva I, Selander T, et al. Variation in severity-adjusted resource use and outcome in intensive care units. Intensive Care Med. 2022;48:67–77. https://doi.org/10.1007/s00134-021-06546-4.

[5] Keene AR, Cullen DJ. Therapeutic intervention scoring system: update 1983. Crit Care Med. 1983;11:1–3. https://doi.org/10.1097/00003246-198301000-00001.

[6] Le Gall J-R, Lemeshow S, Saulnier F. Simplified acute physiology score (SAPS II) based on a European / North American multicenter study. JAMA. 1993;270: 2957–63. https://doi.org/10.1001/jama.270.24.2957.

[7] Conversion rates - Purchasing power parities (PPP) - OECD Data; 2022. https://doi.org/10.1787/1290ee5a-en Accessed on 26 November 2020.

[8] Moser A, Reinikainen M, Jakob SM, Selander T, Pettilä V, Kiiski O, et al. Mortality prediction in intensive care units including premorbid functional status improved performance and internal validity. J Clin Epidemiol. 2022;142:230–41. https://doi.org/10.1016/j.jclinepi.2021.11.028.

[9] Brazzi L, Bertolini G, Arrighi E, Rossi F, Facchini R, Luciani D. Top-down costing: problems in determining staff costs in intensive care medicine. Intensive Care Med. 2002; 28:1661–3. https://doi.org/10.1007/s00134-002-1494-0.

[10] Negrini D, Sheppard L, Mills GH, Jacobs P, Rapoport J, Bourne RS, et al. International Programme for Resource Use in Critical Care (IPOC)–a methodology and initial results of cost and provision in four European countries. Acta Anaesthesiol Scand. 2006;50:72–9. https://doi.org/10.1111/j.1399-6576.2006.00901.x.

[11] Kramer AA, Dasta JF, Kane-Gill SL. The impact of mortality on Total costs within the ICU. Crit Care Med. 2017;45:1457–63. https://doi.org/10.1097/CCM.0000000000002563.

[12] Halpern NA, Pastores SM. Critical care medicine beds, use, occupancy, and costs in the United States: a methodological review. Crit Care Med. 2015;43:2452–9. https://doi.org/10.1097/CCM.0000000000001227.

[13] Rapoport J, Teres D, Zhao Y, Lemeshow S. Length of stay data as a guide to hospital economic performance for ICU patients. Med Care. 2003;41:386–97. https://doi.org/10.1097/01.MLR.0000053021.93198.96.

[14] Rapoport J, Teres D, Lemeshow S, Gehlbach S. A method for assessing the clinical performance and cost-effectiveness of intensive care units: a multicenter inception cohort study. Crit Care Med. 1994;22:1385–91. https://doi.org/10.1097/00003246-199409000-00006.

[15] Nathanson BH, Higgins TL, Teres D, Copes WS, Kramer A, Stark M. A revised method to assess intensive care unit clinical performance and resource utilization. Crit Care Med. 2007;35:1853–62. https://doi.org/10.1097/01.CCM.0000275272.57237.53.

[16] Gyldmark M. A review of cost studies of intensive care units: problems with the cost concept. Crit Care Med. 1995;23:964–72.

[17] Moerer O, Plock E, Mgbor U, Schmid A, Schneider H, Wischnewsky MB, et al. A German national prevalence study on the cost of intensive care: an evaluation from 51 intensive care units. Crit Care. 2007;11:R69. https://doi.org/10.1186/cc5952.

[18] Iapichino G, Radrizzani D, Simini B, Rossi C, Albicini M, Ferla L, et al. Effectiveness and efficiency of intensive care medicine: variable costs in different diagnosis groups. Acta Anaesthesiol Scand. 2004;48:820–6. https://doi.org/10.1111/j.1399-6576.2004.00421.x.

[19] Lefrant J-Y, Garrigues B, Pribil C, Bardoulat I, Courtial F, Maurel F, et al. The daily cost of ICU patients: a micro-costing study in 23 French intensive care units. Anaesth Crit Care Pain Med. 2015;34:151–7. https://doi.org/10.1016/j.accpm.2014.09.004.

[20] Rozeboom PD, Henderson WG, Dyas AR, Bronsert MR, Colborn KL, Lambert-Kerzner A, et al. Development and validation of a multivariable prediction model for postoperative intensive care unit stay in a broad surgical population. JAMA Surg. 2022;157: 344–52. https://doi.org/10.1001/jamasurg.2021.7580.

[21] Pearse RM, Moreno RP, Bauer P, Pelosi P, Metnitz P, Spies C, et al. Mortality after surgery in Europe: a 7 day cohort study. Lancet. 2012;380:1059–65. https://doi.org/10.1016/S0140-6736(12)61148-9.