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EDITORIAL

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ICUs after surgery, mortality, and the Will Rogers effect

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In a recent article in *Intensive Care Medicine*, Gillies and colleagues describe and seek to explain the substantial variation in patient survival following surgery after admission to the intensive care unit (ICU) [1]. At this point, we consider it essentially settled science that health care delivery varies [2, 3], that surgical care varies [4], and that even care within a single payer health care system varies. Gillies et al.'s work echoes this theme. They found a 10 % variation in mortality across the UK among patients admitted to critical care directly from surgery, not explained by measured patient-level characteristics.

What, then, should we learn from this study?

Surgeries, ICUs, and patient flow

A core finding from the work of Gillies et al. suggests that surgical patient mortality among patients admitted directly to critical care services was explained by how hospitals used their ICU beds following surgery, not simply by whether there were ICU beds (or how many), or even by how sick the patients were. Specifically, the number of ICU admissions per 100,000 surgical procedures better explained how mortality varied than did case mix or regional ICU bed provision.

Some hospitals have too few ICU beds for their needs. Building more ICU beds seems like an obvious solution, but Gillies' findings suggest that such a strategy will not necessarily result in lower post-surgical mortality without attention to policies about which patients go to those ICU beds. How the ICU beds are used plays an important role.

We know that patient flow to critical care services matters to patient survival. For example, when the medical ICU is full, the odds of cardiac arrest outside the ICU nearly double [5]. Delays in moving patients to the ICU from the emergency room [6, 7] and from the floor [8–13] have demonstrated harm to patients. Gillies' work extends this to the perioperative space.

If this finding is correct, there may be room to improve surgical mortality through changes in ICU allocation and, potentially more importantly, through patient flow—a powerful policy opportunity.

But what if we can't afford to build more ICU beds? Before we rush to an ICU building boom, we should note that increasing ICU capacity does not always require building new ICU beds. We know that inattention to patient flow leads to rationing without contemplation [14], and that improving flow builds capacity without building beds. We also know that tools from quality improvement, industrial improvement techniques such as Lean, and operations management have been used to successfully improve ICU capacity without capital expense [15]. More sophisticated tools such as queuing models and discrete event simulation are increasingly playing a role in ICU patient flow management [16].

In the perioperative realm, we also know that demand smoothing plays an important role. By anticipating ICU bed need following surgery and smoothing the process of entry to a higher level of care, patients may be better

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served. For example, hospitals may consider closer examination of barriers to critical care entry from the surgical theater, whether those are barriers to transitioning patients to the floor, availability of staff at different times of day, or physician and physician extender coverage in the ICU. While health care delivery innovations at the hospital level have been described by Uma Kotagal and her team [17], there may be an opportunity here to deliver safer postsurgical care more broadly.

A word of caution: what would Will Rogers say?

Despite the potential policy implications of this work, however, we would offer one significant word of caution. Analysis of large delivery systems must wrestle with the often-intractable challenges of selection bias. In this case, Gillies and colleagues' work raises the specter of the Will Rogers phenomenon. This epidemiological phenomenon gets its name from the humorist Will Rogers, who reportedly said, "When the Okies left Oklahoma and moved to California, they raised the average intelligence in both states."

This phenomenon can happen whenever a group of patients moves between one category and another. For mortality, for example, it occurs whenever the group that "leaves" one category has a higher mortality than those patients who are left behind, but a lower mortality than the group they "join." The mortality rate of both groups will then artifactually decrease. We have laid out a concrete, if implausible, thought experiment in Table 1 to show how this could work. Other studies have demonstrated this phenomenon—the movement over time or between groups of patients into and out of a disease stage—among patients with lung cancer [18] and among patients moving between insurance plans [19]. It can have meaningfully large effects.

With regards to delivery of critical care services following surgery, it could be that "if you build it, they will come," and that adding more ICU beds just adds less sick patients to the ICUs, without changing overall hospital mortality. The authors' efforts to control for patient-level severity of illness in this study demonstrates their understanding of the challenges of their complicated endeavor: health care delivery systems are invariably complex and drawing accurate causal inferences from large datasets represents the important and underappreciated central challenge of health care delivery science. The existing data that were collected cannot, unfortunately, address this one way or the other, because the authors did not have access to whole-hospital mortality for patients not admitted to ICU. This does not mean that Gillies' findings are incorrect, but until we have more data we should have some caution in applying them to broad policy decisions.

Table 1 A thought experiment about the Will Rogers effect in a hypothetical hospital

	2014		2015	
	n	Mortality (%)	*n*	Mortality (%)
Went to ICU	50	20	313	16
Did not go to ICU	950	10	688	8
Total hospital	1000	10.5	1000	10.5

In this example, the hospital builds more ICU beds between 2014 and 2015. It is therefore able to move a large number of patients into the ICU who formerly went to the wards. The total number of patients at the hospital does not change, nor does the overall hospital mortality rate. But both the ICU mortality and the non-ICU mortality fall by 20 %. This is a concrete (if implausible) example of the epidemiological phenomenon known as the Will Rogers effect

What should we take away from this study? Should we ignore Gillies and colleagues' findings? Absolutely not. We should conclude that not only are researchers continuing to push the bounds of the field of health care delivery science to measure and improve how we delivery care to patients but significant methodological challenges like the Will Rogers effect must be carefully studied as well. And in the meantime we should be attentive to the fact that how we use ICU beds matters, both in the medical and surgical realms.

Compliance with ethical standards

Conflicts of interest The authors have no financial conflicts related to the material in this manuscript.

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ORIGINAL

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Regional variation in critical care provision and outcome after high-risk surgery

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Take-home message: Regional variation in mortality for patients admitted to ICU after high-risk surgery exists within a uniform healthcare system and persists after adjustment for case mix. Variation in absolute regional provision of intensive care beds (ICU beds per 100,000 population) did not appear to explain this finding; ICU bed utilisation (ICU admissions per 100,000 surgical procedures) better explains the observed variation and is associated with improved outcome.

Electronic supplementary material
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Abstract *Purpose:* Evidence of variation in mortality after surgery may indicate preventable postoperative death. We sought to determine if regional differences in outcome were present in surgical patients admitted to critical care in the UK. *Methods:* We extracted data on admission characteristics, case mix and outcome of all patients admitted to UK critical care units following surgery for the calendar year of 2009. We also used publicly held data on regional population, volume of surgery and bed provision. Multilevel regression analysis was used to adjust for the effects of case mix and regional critical care bed provision on acute hospital mortality. *Results:* A total of 16,147 patients admitted to critical care following surgery were included in this analysis. Median odds ratio (MOR) was used to describe regional-level variance in acute hospital mortality. Significant variation was identified (MOR 1.14; 95 % CI 1.07, 1.28) and persisted following adjustment for case mix (MOR 1.10; 95 % CI 1.04, 1.25) and regional critical care bed provision (MOR 1.09; 95 % CI 1.04, 1.24). Critical care bed utilisation (surgical critical care admissions per 100,000 surgical procedures) seemed to better explain this observation (MOR 1.03; 95 % CI 1.00, 29.26) and was associated with statistically significant reduction in mortality (OR 0.91; 95 % CI 0.85, 0.97; $p = 0.01$). *Conclusion:* Significant regional variation in hospital mortality for patients admitted to critical care following surgery was observed. Critical care bed utilisation seemed to better explain this observation and was associated with improved outcome.

Keywords Epidemiology · Intensive care · Critical care · General surgery

Introduction

More than 230 million patients undergo surgery worldwide each year and numbers are increasing [1]. Estimates of hospital mortality following high-risk surgery range from 1 to 4 %, translating to a minimum of 2.3 million deaths each year worldwide. Postoperative complication rates of up to ten times this figure have been reported and

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these have been shown to influence longer-term survival [2]. Even a low incidence of preventable harm could have considerable effects on survival and quality of life; however, recent studies suggest that postoperative complication rates have remained constant in recent years [3]. Thus, improvements in peri- and postoperative care could have substantial long-term benefits.

Despite differences in preoperative patient risk factors and complexity of surgical procedure, care provided to high-risk surgical patients is frequently similar to those at lower risk. The reasons for this remain unclear but limited access to healthcare resources including critical care is frequently cited as an issue [4, 5]. There is growing evidence linking variation in the standards of care with patient outcomes following surgery [4–7]. The American College of Surgeons' National Surgical Quality Improvement Programme (NSQIP) reported a twofold variation in mortality between hospitals for patients experiencing postoperative complications [8]. Other research indicates international variation in mortality between European and North American countries [4, 7]. Within the UK National Health Service (NHS), variation in postoperative mortality has been reported both between hospitals and by day of the week of surgery [5, 6, 9]. Many factors could contribute to the observed differences in postoperative mortality but a recent UK study suggested that access to radiological services and access to critical care beds were significantly different between the best and worst performing hospitals [10, 11].

Although variation in access and use of critical care resources could influence outcome from high-risk surgery, there is little objective evidence to support this hypothesis [4, 7, 11, 12]. This study set out to explore whether regional variation in outcome for surgical admissions to critical care is explained by variation in case mix, critical care bed provision and utilisation.

Methods

Analyses were conducted for the year 2009. Regions were defined as either devolved nation (Scotland, Wales, Northern Ireland) or in England by Strategic Health Authority (SHA) (Supplementary File 1). The study protocol was reviewed by the Chairs of South East Scotland Research Ethics Committees 01 and 02; full ethics submission was deemed unnecessary.

UK data sources

Population and hospital bed data were extracted from the Office for National Statistics, Health and Social Care Information Centre Hospital Episode Statistics or equivalent [13, 14]. Critical care beds were defined as beds in adult, general intensive care units or in mixed intensive/high dependency care (level 3/level 2) units (HDUs) and excluded specialist units (e.g. cardiothoracic, neurosciences, etc.) or units solely delivering high dependency (level 2) care. Levels of critical care, i.e. level 3 (intensive care) and level 2 (high dependency care), were defined according to the UK Intensive Care Society [15].

Data on surgical procedures used Office of Population Censuses and Surveys-4 (OPCS4) codes, a standard alphanumeric coding system of surgical and other procedures.

Surgical admissions to critical care were defined as those admitted directly to the critical care unit from an operating theatre or post-anaesthetic recovery room and receiving intensive (level 3) care in the first 24 h. Data on admissions for calendar year 2009 were derived from the ICNARC Case Mix Programme (CMP) (England, Wales and Northern Ireland) and from the Scottish Intensive Care Society Audit Group (SICSAG) databases. These data undergo extensive validation prior to pooling into the national clinical audit databases. Admissions under the age of 16 years, previously admitted to the critical care unit within the same hospital stay or with missing outcome data were excluded. Admissions following cardiac, neuro or transplantation surgery, or with burns were also excluded; these patients have well-defined postoperative care pathways involving routine admission to critical care. Acute physiology and chronic health evaluation II (APACHE II) surgical diagnostic groups were used as this offered greater consistency across data sets. After exclusion of unwanted groups 29 out of 50 surgical APACHE II diagnostic categories remained. These codes were then grouped by type of surgery or disease process by two authors (MG and RP). Any disparity was resolved by consensus of all other authors.

Data management and analysis

A statistical analysis plan was agreed a priori.

For surgical admissions to critical care, demographic, severity of illness and outcome data were extracted. Acute severity of illness was assessed by the APACHE II acute physiology score (APS). Prior cardiopulmonary resuscitation (within 24 h of admission to critical care) and urgency of surgery were also extracted. Mortality at both critical care unit and acute hospital discharge and duration of critical care unit and acute hospital stay were calculated. Critical care bed provision was defined as the number of beds in adult ICUs or ICU/HDUs in each region per 100,000 adult population.

Crude acute hospital mortality by region is presented in a funnel plot for all surgical admissions to critical care and for three predefined subgroups: those undergoing emergency surgery on the gastrointestinal (GI) tract; those undergoing elective surgery for abdominal neoplasm; and

those undergoing surgery for trauma. To explore the variation in acute hospital mortality between regions, the median odds ratio (MOR) was calculated [16, 17]. The aim of the MOR is to convert the regional-level variance to a more intuitive OR scale. If the MOR is 1, then there is no variation between regions. If there is considerable variation between regions, then the MOR will be large.

Three multilevel logistic regression models were fitted for acute hospital mortality and the random effects of region were compared at each stage using the MOR. Stages were defined as null model (adjusted for the random effects of region and critical care unit), case mix model (additionally adjusted for patient-level covariates: age; gender; CPR within 24 h prior to admission; surgical urgency; reason for admission and APACHE II APS) and full model (additionally adjusted for regional-level critical care bed provision covariate: adult general critical care beds per 100,000 adults). As a post hoc sensitivity analysis, the model was adjusted for regional-level critical care bed utilisation covariate (adult surgical admissions to critical care per 100,000 surgical procedures). This was calculated by expressing the number of postoperative critical care admissions per region (as defined above) by the total volume of surgery for that region; where necessary the total number of surgical admissions to critical care was extrapolated. A detailed account of this is provided in Supplementary File 2. Analyses were performed using Stata SE 10.1 (StataCorp, TX, USA).

Results

Data on 16,147 patients from 207 critical care units was extracted. The process for identifying patients suitable for inclusion in the study is outlined in Fig. 1. Categorical data are presented as number and percentage, continuous data as mean (standard deviation, SD) where normally distributed or median (interquartile range, IQR) where not normally distributed.

Regional variation: populations and beds

Mean regional adult population (16 years and over) was 4.8 million and ranged from 1.8 million (Northern

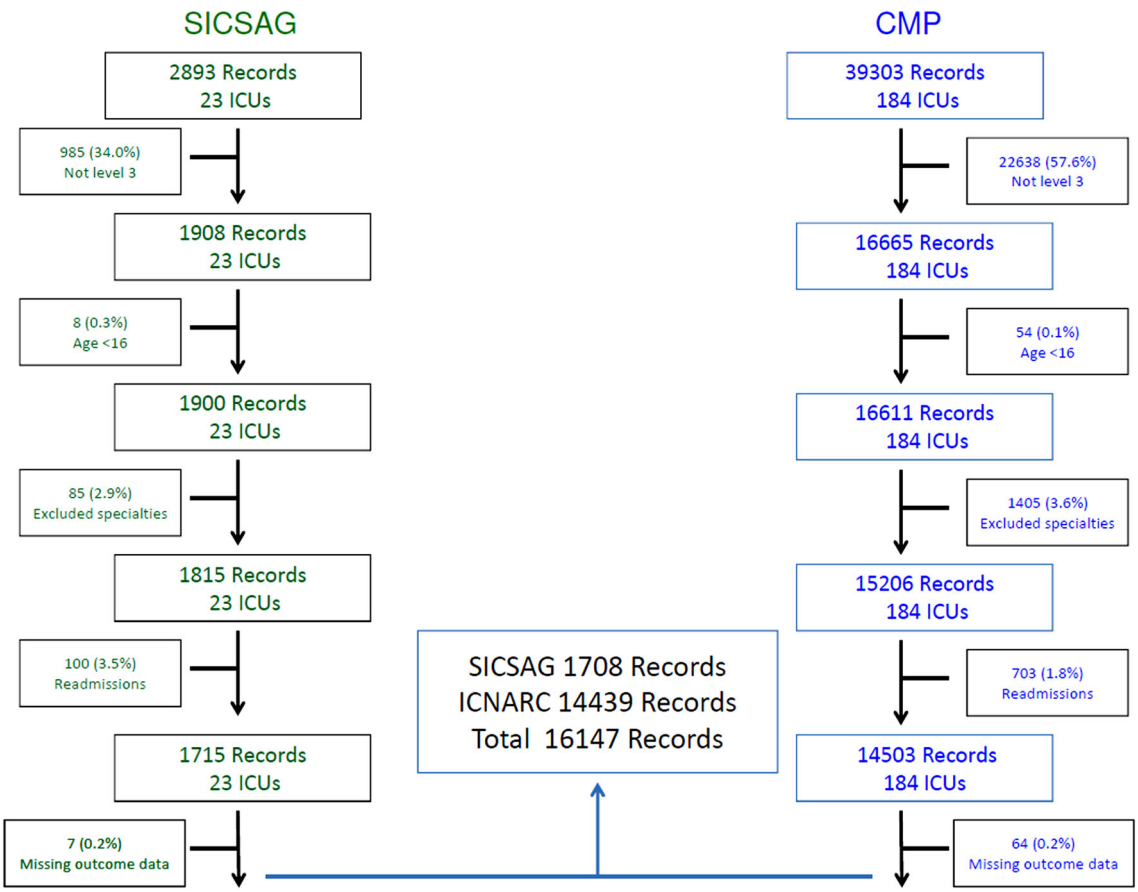

Fig. 1 Flow diagram of study cohort selection (*SICSAG* Scottish Intensive Care Society Audit Group, *CMP* case mix programme, *ICNARC* Intensive Care National Audit and Research Centre, *ICU* intensive care unit)

Ireland) to 7.8 million (London SHA). Mean regional number of surgical procedures per 100,000 adult population was 16,124 and ranged from 12,536 (South Central SHA) to 19,779 (North East SHA). The mean number of surgical critical care admissions was 1265 and ranged across regions from 695 (Northern Ireland) to 1754 (London SHA). Extrapolated admissions were 1630 (mean) and ranged across regions from 695 (Northern Ireland) to 3700 (London SHA) (Table 1). The mean extrapolated number of surgical admissions to adult general critical care per 100,000 surgical procedures was 175 and ranged from 107 (North West SHA) to 226 (East Midlands SHA) (Table 1).

The number of acute hospital beds per 100,000 adult population varied across regions from 193 (South Central SHA) to 329 (Scotland) with a mean of 246. The number of adult general critical care beds varied more than twofold between regions; the mean number per 100,000 adult population was 4.9 and ranged from 3.4 (East of England SHA) to 7.2 (London SHA). Mean adult general critical care beds per 100,000 surgical procedures, was 24.9 and ranged from 17.7 (East of England SHA) to 39.6 (Wales) (Table 1).

Regional variation: surgical admissions to critical care

Age, gender and acute severity of illness were similar across regions. However, the percentage of surgical admissions to critical care following CPR varied from 1.6 % (West Midlands SHA) to 4.6 % (Yorkshire and Humber SHA) and those following emergency/urgent surgery from 52.4 % (London SHA) to 79.6 % (Yorkshire and the Humber SHA) (Supplementary File 2). There was evidence of regional variation in the surgical specialty groups with, for example, an almost twofold variation in surgery for neoplasm, for major vascular surgery and for surgery following trauma (Supplementary File 2).

Crude critical care mortality ranged from 12 % (London SHA) to 19 % (North West SHA) across regions. Crude acute hospital mortality varied by more than 10 % (absolute) across regions; this was observed for all surgical admissions to critical care (Table 2; Fig. 2) and for the predefined subgroups with the exception of trauma (Fig. 3). Overall, median critical care length of stay was 2.7 days for critical care survivors and 2.5 days for critical care unit non-survivors but the IQR was wide for the latter (0.8, 7.5). Median acute hospital length of stay ranged from 17 to 24 days for acute hospital survivors and from 9 to 13 days for acute hospital non-survivors (Table 2).

Impact of critical care bed provision and utilisation on regional variation in outcome

Using multilevel logistic regression, the MOR for regional variation in acute hospital mortality was 1.14 (95 %

Table 1 Population, volume of surgery and bed provision by region

Region	Total adult population	Surgical procedures	Surgical procedures per 100,000 adult population	Number (extrapolated) of admissions	Surgical critical care admissions per 100,000 surgical procedures	Acute hospital beds	Acute hospital beds per 100,000 adult population	Adult general critical care beds	Adult general critical care beds per 100,000 adults	Adult general critical care beds per 100,000 surgical procedures
East Midlands SHA	4,451,240	652,014	14,648	1474 (1600)	226.1	9267	208.20	148	4.1	22.70
East of England SHA	5766,625	890,500	15,442	1108 (1400)	124.4	11,771	204.12	158	3.4	17.74
London SHA	7,753,555	1277,092	16,471	1757 (3700)	137.6	17,926	231.20	448	7.2	35.08
North East SHA	2,584,262	511,132	19,779	1024 (1300)	200.3	7690	297.57	141	6.6	27.59
North West SHA	6,897,905	1,267,002	18,368	1357 (1900)	107.1	18,622	269.97	299	5.3	23.60
Northern Ireland	1,788,900	343,235	19,187	695 (695)	202.5	4255	237.86	78	5.5	22.72
Scotland	5,194,000	779,524	15,008	1754 (1754)	225.0	17,075	328.74	173	4.0	22.19
South Central SHA	4,095,376	513,412	12,536	1048 (1300)	204.1	7911	193.17	121	3.7	23.57
South East Coast SHA	4,340,342	582,796	13,427	947 (1600)	162.5	8794	202.60	160	4.5	27.45
South West SHA	5,231,243	922,509	17,635	1770 (2100)	191.9	12,993	248.37	168	3.9	18.21
Wales	3,038,872	403,913	13,292	797 (1000)	197.3	8449	278.03	160	6.5	39.61
West Midlands SHA	5.431,079	906,333	16,688	1401 (1401)	154.6	13,112	241.43	221	5.0	24.38
Yorkshire and the Humber SHA	5,258,114	900,679	17,129	1316 (1500)	146.1	13,126	249.62	172	4.0	19.10
Mean	4,756,270	765,395.5	16,124	1265 (1635)	175	11,615	245.5	188.2	4.9	24.9

SHA Strategic Health Authority

Table 2 Outcomes and resource use by region

	Critical care unit mortality (%) [*N*]	Acute hospital mortality (%) [*N*]	Critical care length of stay		Acute hospital length of stay	
			Unit survivors, median (IQR)	Unit non-survivors, median (IQR)	Survivors, median (IQR)	Non-survivors, median (IQR)
East Midlands SHA	193 (13.1) [1474]	291 (19.7) [1474]	2.6 (1.2, 5.2)	2.9 (1.0, 8.0)	17 (10, 35)	9 (4, 22)
East of England SHA	196 (17.7) [1108]	310 (28.0) [1108]	2.8 (1.52, 5.7)	1.9 (0.7, 6.2)	21 (12, 41)	10 (3, 23)
London SHA	211 (12.0) [1757]	331 (18.8) [1757]	2.5 (1.1, 5.4)	3.0 (0.9, 9.9)	19 (11, 35)	13 (4, 30)
North East SHA	135 (13.2) [1024]	248 (24.2) [1024]	2.1 (1.0, 4.9)	2.3 (0.9, 7.3)	21 (11, 41)	12 (5, 36)
North West SHA	258 (19.0) [1357]	395 (29.1) [1357]	3.7 (1.9, 8.0)	3.1 (0.9, 9.0)	24 (13, 45)	11 (4, 28)
Northern Ireland	105 (15.1) [695]	165 (23.7) [695]	2.9 (1.7, 5.7)	3.3 (0.9, 8.6)	20 (12, 36)	10 (4, 24)
Scotland	216 (12.3) [1754]	385 (21.9) [1754]	1.9 (0.9, 3.9)	2.4 (0.8, 6.4)	20 (12, 34)	12 (5, 24)
South Central SHA	143 (13.6) [1048]	215 (20.5) [1048]	2.2 (1.1, 4.8)	2.1 (0.7, 5.5)	17 (10, 34)	10 (4, 22)
South East Coast SHA	117 (12.4) [947]	183 (19.3) [947]	3.0 (1.8, 6.0)	2.5 (1.1, 5.3)	17 (10, 32)	10 (4, 19)
South West SHA	251 (14.2) [1770]	398 (22.5) [1770]	2.7 (1.4, 5.1)	2.2 (0.7, 5.9)	18 (10, 33)	9 (3, 19)
Wales	130 (16.3) [797]	218 (27.4) [797]	3.0 (1.6, 6.4)	2.2 (0.8, 7.3)	18 (11, 35)	11 (3, 31)
West Midlands SHA	218 (15.6) [1401]	321 (22.9) [1401]	3.1 (1.7, 6.9)	2.6 (0.8, 9.7)	19 (11, 38)	11 (4, 22)
Yorkshire and the Humber SHA	240 (18.2) [1316]	363 (27.6) [1316]	2.8 (1.4, 6.6)	2.5 (0.8, 7.2)	22 (11, 44)	10 (3, 22)
Total	2413 (14.7) [16,448]	3823 (23.2) [16,448]	2.7 (1.3, 5.7)	2.5 (0.8, 7.5)	19 (11, 37)	11 (4, 24)

SHA Strategic Health Authority

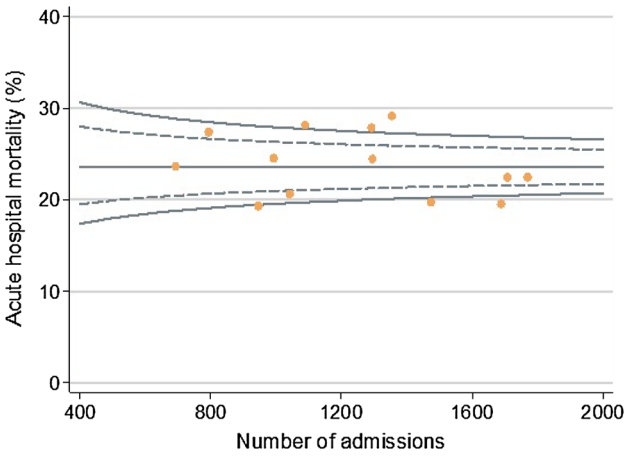

Fig. 2 Funnel plot of crude acute hospital mortality by region. *Broken lines* 2 standard deviations (SD), *continuous lines* 3 SD

CI 1.07, 1.28). This decreased when the model was adjusted for case mix (MOR 1.10; 95 % CI 1.04, 1.25) with a further small decrease when critical care bed provision was included (MOR 1.09; 95 % CI 1.04, 1.24); the effect of critical care bed provision was not statistically significant (OR 1.04 per one additional critical care bed per 100,000 adults; 95 % CI 0.97, 1.11; $p = 0.25$) (Fig. 4). Data is presented for both region and unit. The analysis was only undertaken for the full cohort as the subgroups lacked sufficient sample size.

As a post hoc sensitivity analysis, the full model was repeated adjusting for surgical admissions to critical care per 100,000 surgical procedures (in place of critical care bed provision) as a measure of critical care bed utilisation. This model seemed to better explain the variation observed in acute hospital mortality across regions (MOR 1.03; 95 % CI 1.00, 29.26) and the effect of critical care bed utilisation was statistically significant (OR 0.91 per 50 additional surgical admissions to critical care per 100,000 surgical procedures; 95 % CI 0.85–0.97; $p = 0.01$) (Fig. 4). These results hold when the analysis is repeated in those admissions that did not have CPR within 24 h prior to admission (Supplementary Files 3 and 4).

Discussion

We found significant regional variation in acute hospital mortality within the UK for patients receiving level 3 care in an adult, general critical care unit following surgery. This finding was observed both overall and in clinically relevant subgroups. Variation persisted after adjustment for case mix and regional differences in critical care bed provision. Regional variations in the patterns of utilisation of critical care resources following surgery were also observed and, in a

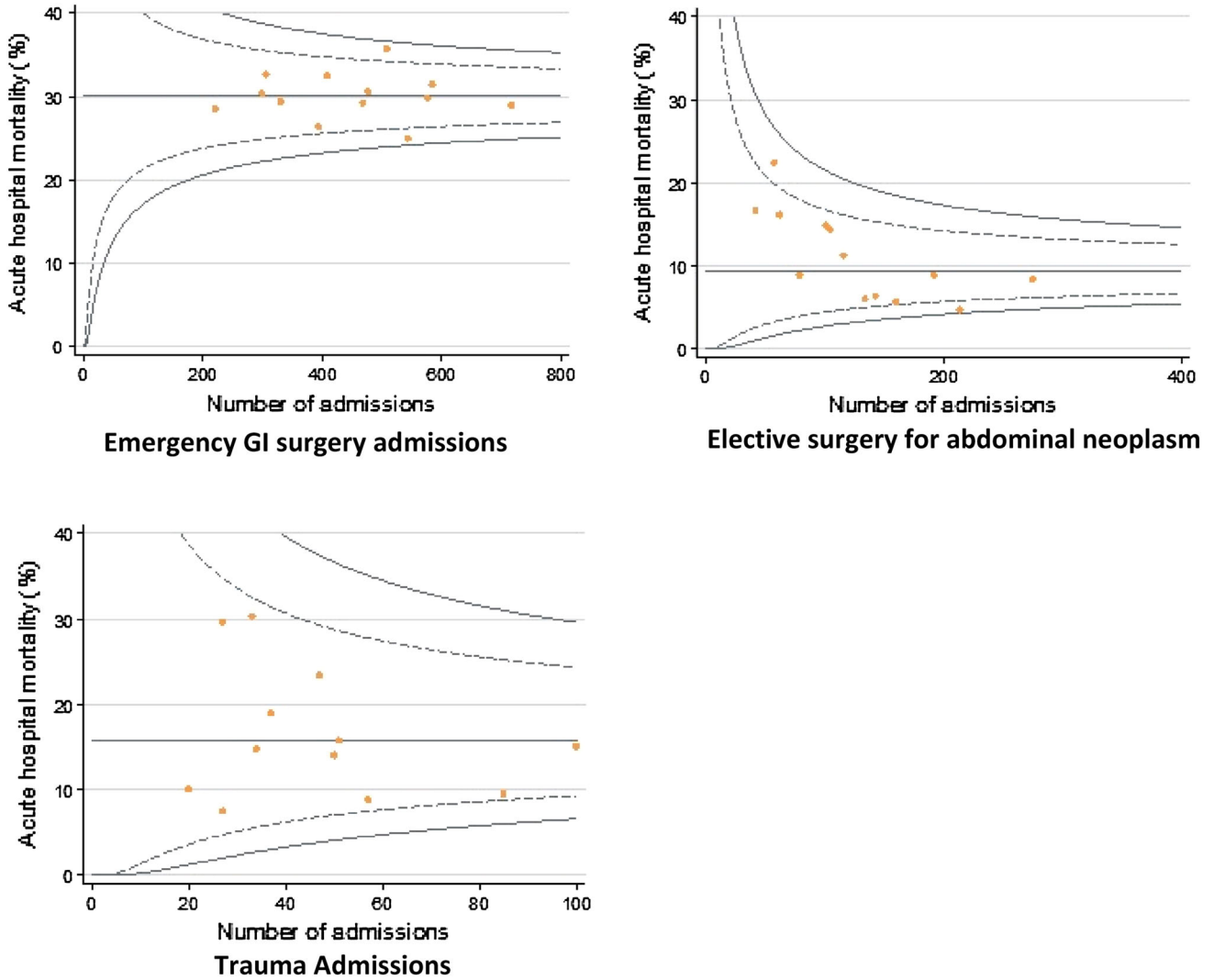

Fig. 3 Funnel plot of crude acute hospital mortality by region, for subgroups (*GI* gastrointestinal). *Broken lines* 2 standard deviations (SD), *continuous lines* 3 SD

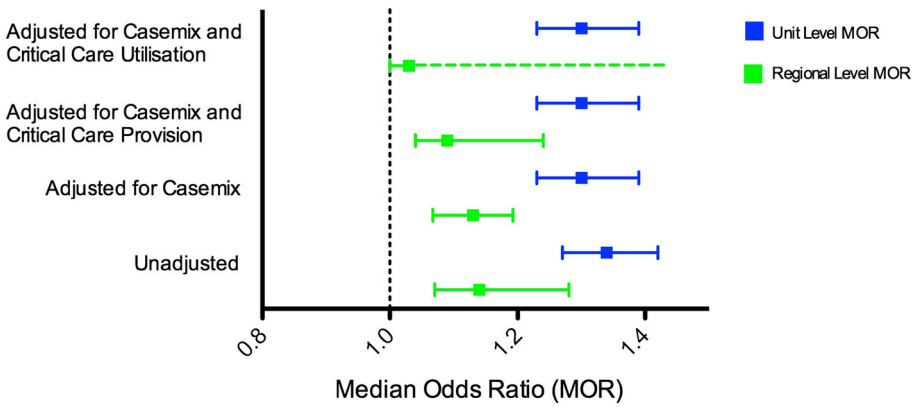

Fig. 4 Regional and unit variation in acute hospital mortality after adjustment for case mix, care bed provision and critical care utilisation. Reported as median odds ratio (MOR)

post hoc adjusted analysis, explained much of the variation in acute hospital mortality. These findings could indicate important variations in use of critical care that affect survival.

The EuSOS study reported variation in surgical outcome between European nations, and suggested that patient co-morbidities and surgical factors have the highest effect on mortality. The relationship between provision of critical care beds and international differences in outcomes was unclear in this study, and healthcare-specific differences such as post anaesthesia care units or differences in general ward care could partly explain this variation [7]. In EuSOS 73 % of patients that died following surgery were never admitted to critical care at any time and there is no evidence that routine admission to critical care following elective surgery improves perioperative morbidity or mortality. Variation in outcome after surgery within the UK National Health Service (NHS) has been demonstrated in other studies. A recent study of outcome after emergency laparotomy in 35 NHS Trusts in England found mortality varied between 3.6 and 41.7 %; of note between 0 and 69 % of these cases received postoperative care on a normal ward [6]. This variation also appears to extend to elective surgery; for example in another study, a "weekday" effect was demonstrated on outcome after four types of elective procedure. The authors of this paper proposed that hospital organisational factors might explain this phenomenon [9]. Another study found that high mortality outlier hospitals for emergency surgery had significantly reduced provision of critical care beds, although this finding did not appear to extend to high dependency bed provision [5].

In our study, in a single large healthcare system, the absolute provision of critical care beds did not explain the observed variation in outcome, but actual utilisation of critical care resource, expressed as a proportion of surgical cases, was more relevant. This study only included patients admitted directly from the operating theatre or recovery area; in this group the need for critical care is likely to be most urgent and hence have the biggest impact on outcome. Systematic differences in critical care utilisation between regions could explain these differences. For example, one explanation could be that higher critical care admission rates resulted in less unwell patients admitted routinely for postoperative care. Conversely in regions with very low utilisation, only the sickest patients were admitted, resulting in higher mortality. Our findings may indicate that regions in which critical care admission was more integrated into usual care pathways have reduced acute hospital mortality; however, a large linked data set of all inpatient surgical procedures would be required to answer this question definitively and such a data set does not currently exist in the UK. Although we cannot exclude important effects from unmeasured confounding, if regional mortality variation is in part attributable to patterns of critical care use, then some deaths may be preventable by adopting patient pathways similar to regions with lowest mortality. The mechanism via which greater use of critical care may improve outcomes after high-risk surgery cannot be determined from our study. There is evidence that critical care interventions (e.g. fluid therapy) may improve outcome in these patients, especially when applied pre-emptively [18, 19]. Volume of surgery, preoperative risk assessment, access to imaging modalities, timeliness of surgery and the presence of senior clinical staff are also likely to have a significant impact on outcome. It is possible that more routine use of critical care directly and indirectly improves care in these areas.

Strengths of our study are the use of large, high-quality data sets, national coverage and a low incidence of missing outcome data [20]. Care was taken to carefully match the two databases utilised, to minimise the chance of bias. There was broad consistency in gender, age and severity of illness scoring between regions, and our estimates for both volume of surgery and provision of critical care were consistent with other studies [1, 11]. We also employed robust methodology to construct our model and describe regional-level variance [17].

There were several potential sources of bias in our study. Although our data set had 100 % coverage of all adult general critical care units in Scotland, Northern Ireland and West Midlands SHA in 2009, the CMP covered 76 % of adult, general critical care units in the remainder of England and Wales. To mitigate this we extrapolated the regional numbers so our bed provision and bed utilisation adjustments are as representative as possible. Further bias may have a risen from the so-called Will Rodgers phenomenon or stage migration where the routine admission of less sick patients to critical care could have reduced mortality in both critical care and the wards but without changing overall hospital mortality [21]. Other confounding factors could include the regional effects of deprivation, ethnicity, differences in complexity of surgery and skill of surgical and other staff and regionalisation of high-risk surgery in high-volume centres; this might be particularly the case in London, which hosts a high number of tertiary and quaternary services. Only data from one calendar year was used due to coding changes in SICSAG and CMP data sets. Finally, our study was based on data held by different agencies, although we endeavoured to standardize the extracts as much as possible.

A recent King's Fund Report with specific reference to surgical care highlighted that variation in healthcare is expected and unlikely to be eradicated, but a priority is identifying and eradicating unwanted variation that adversely affects patient outcomes [22]. With the intense scrutiny currently applied to outcomes after surgery, the effect of critical care and other hospital organisational factors on patient outcome is likely to have important effects on outcome. The wide variation in acute hospital

mortality observed in this analysis suggests that unwanted variation may exist, and that optimising the integration of critical care into surgical care pathways may improve outcomes for this group.

Conclusion

Regional variation in acute hospital mortality for postoperative patients admitted to adult, general critical are units for level 3 care exists in the UK, which is not explained by variation in case mix and critical care bed provision, but may relate to critical care bed utilization. These data suggest that optimising postoperative surgical care pathways for high-risk patients, especially in relation to critical care use, could reduce acute hospital mortality.

Compliance with ethical standards

Conflicts of interest MG holds a Chief Scientist Office (Scotland) NHS Research Scheme Fellowship. RP reports grants and personal fees from Nestle Health Sciences, personal fees from Massimo Inc., personal fees from Edwards Life Sciences, and equipment loans from LiDCO Ltd. The other authors confirm they have no conflict of interest.

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