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Processes of care in surgical patients who died with hospital-acquired infections in Australian hospitals

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Background: Infection may complicate surgical patients' hospital admission. The effect of hospital-acquired infections (HAIs) on processes of care among surgical patients who died is unknown.

Aim: To investigate the effect of HAIs on processes of care in surgical patients who died in hospital.

Methods: Surgeon-recorded infection data extracted from a national Australian surgical mortality audit (2012–2016) were grouped into HAIs and no infection. The audit included all-age surgical patients, who died in hospital. Not all patients had surgery. Excluded from analysis were patients with community-acquired infection and those with missing timing of infection. Multivariate logistic regression was used to determine the adjusted effects of HAIs on the processes of care in these patients. Costs associated with HAIs were estimated.

Findings: One-fifth of surgical patients who died did so with an HAI (2242 out of 11,681; 19.2%). HAI patients had increased processes of care compared to those who died without infection: postoperative complications [51.0% vs 30.3%; adjusted odds ratio (aOR): 2.20; 95% confidence interval (CI): 1.98–2.45; $P < 0.001$]; unplanned reoperations (22.6% vs 10.9%; aOR: 2.38; 95% CI: 2.09–2.71; $P < 0.001$) and unplanned intensive care unit admission (29.3% vs 14.8%; aOR: 2.18; 95% CI: 1.94–2.45; $P < 0.001$). HAI patients had longer hospital admissions and greater hospital costs than those without infection.

Conclusion: HAIs were associated with increased processes of care and costs in surgical patients who died; these outcomes need to be investigated in surgical patients who survive.

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Introduction

The Australian public in-hospital perioperative mortality rate in 2013 was 0.36% (3395 deaths per 952,993 surgical separations) [1]. However, the number of patients admitted to both public and private hospitals who died in hospital with a hospital-acquired infection (HAI) present is unknown. An HAI is an infection resulting from contact with health institutions and their services, e.g. ventilator-associated pneumonia, surgical site infection, urinary tract or other catheter-related infections [2,3]. HAIs are considered potentially preventable and may result in death [3—7]. The rate of sepsis-related mortality for patients admitted to intensive care units (ICUs) in Australia and New Zealand in the ten years to 2012 was 24.3% [8]. The effect of infection on patient morbidity, mortality, length of hospital stay (LOS) and costs is known [4,9,10]. Reports usually refer to medical patients rather than to surgical patients and when processes of care comparisons are made, it is in patients who survive [11—13]. Associations of HAIs with processes of care are infrequently reported with mortality as the key indicator. The effect of HAIs on possesses of care in surgical patients who die with an infection is unknown.

To assess the effects of HAIs on the processes of care across all surgical specialties, we analysed reported process of care measures: reoperation, unplanned ICU admission, fluid balance alterations and LOS [13—20].

Using a surgical mortality dataset, we aimed to determine the differences in the processes of care in surgical patients who died with HAIs and those who died without infection. Secondary aims were to determine the distribution of HAIs in the surgical subspecialties and whether there was a difference in healthcare costs.

Methods

Audit inclusion criteria

This retrospective cross-sectional investigation considered the processes of care in surgical patients of all ages who died in hospital. We analysed Australian data collected by a national Audit of Surgical Mortality (a surgical peer-review audit and feedback programme administered by the Royal Australasian College of Surgeons: RACS) between January 2012 and March 2016. Data were from 189 hospitals from all states and territories except for New South Wales (data not available at the time of analysis). The audit's governing structures have been described previously [21]. It is a quality assurance activity designed to exclude surgical patients who survive. The inclusion criteria are death of an inpatient of any age who was either admitted under a surgeon (even if no operation occurred) or admitted medically but underwent an operation. An operation is a clinical intervention that is surgical in nature, carries an anaesthetic risk, requires specialized training and/or requires special facilities or services available only in a specialized care setting.

Audit process and data collection

The audit process is initiated when health information managers notify the audit of in-hospital deaths while following standard hospital reporting protocols. The deaths are reported to the audit independently of the treating surgeon [22]. The treating surgeon completes a standard surgical case form which consists of 25 questions with dichotomous, categorical, quantitative, and limited free-form responses. Not all questions are answered on each case form. Surgeon-supplied data have previously been validated [23]. All cases are peer-reviewed. Peer reviewers are qualified in the same surgical specialty as the treating surgeon, are from a different geographical area, and are blinded to the treating surgeon, patient, and hospital.

Qualified privilege and ethical approval

The RACS-administered audit is an Australian Government gazetted quality improvement committee and has protection under the Commonwealth Qualified Privilege Scheme under part VC of the Health Insurance Act 1973 (25 July 2016). This permits auditing of surgical mortality using an external two-level peer-review process. As such, individual hospital ethical approval was not required and no ethical review board approval was sought.

Infection data extraction

Only cases that had completed the audit process were included. Data extracted from the audit dataset included: patient demographics, surgical variables, processes of care and infection. Patient demographics included: age, sex, admission status, presence of comorbidities, malignancy status, American Society of Anaesthesiologists (ASA) class. Surgical variables included the specialty of the treating surgeon and postoperative complications (other than infections; infections in the perioperative period were counted separately). Processes of care included: delay in surgical diagnosis ('missed, wrong, or delayed diagnosis' as detected by some subsequent definitive test), operation(s), ICU admission, unplanned ICU admission, unplanned return to theatre, and presence of fluid balance alteration (overload or dehydration) [24]. Infections included information on the onset of the infection (acquired during admission) and the infective organism. The onset of infections during the admission was considered as hospital-acquired. Cases were excluded if the patient was admitted with a community-acquired infection or if onset of infection data were missing. All the reported outcomes were the professional opinions of the treating surgeons. The measured processes of care could be potential confounders of each other.

Statistical analysis

Continuous variables are presented as medians with interquartile ranges and categorical variables as frequencies with percentage. The association between patient demographics, clinical characteristics and infection was investigated using logistic regression analysis. First univariate, then multivariate, models were constructed. Multivariate logistic regression models were adjusted for age, gender, ASA class, and the presence of comorbidities. Univariate effect estimates are presented as odds ratio (OR) with 95% confidence interval (CI), and multivariate estimates as adjusted OR (aOR) with 95% CI. The association between infection, fluid balance and LOS was investigated using median regression due to the skewed nature of the LOS variable. The effect estimate is presented as median difference (95% CI). Missing data were not imputed. Significance values were based on two-tailed tests, with $P < 0.05$ considered significant. All data were analysed using IBM SPSS Statistics v22 (IBM Corporation, Armonk, NY, USA).

Cost estimation

Hospital costs were estimated from the mean daily Australian hospital cost ($1839), multiplied by the average LOS (2.7 days) for admitted acute care patients, expressed in Australian dollars (2013/14) [25]. The mean daily hospital cost reflects: emergency/medical/surgical rooms; board, ICU; nursing and allied health; pharmacy; supplies and prosthesis; pathology; diagnostic imaging; operating room charges and depreciation [25]. Costs exclude physician/surgeon charges.

Results

One-third (3996 out of 11,681; 34.2%) of surgical patients in the Australian Audit of Surgical Mortality dataset died with a clinically significant infection, and one-fifth died with an HAI (2242 out of 11,681; 19.2%). Patients with missing timing of infection data ($N = 148$) and with community-acquired infections were excluded ($N = 1606$) (Figure 1). Patient care was significantly more complex for those with HAI than those without infection – higher risks of fluid balance alteration, unplanned ICU admission, delay in surgical diagnosis, and postoperative complications (Table I). HAIs increased with age from 30 years with 87.9% of HAI patients being aged ≥60 years (Table II).

All surgical specialties are reported (Table III) with responses from 98% of Australian surgeons (189 hospitals). The specialties with the highest prevalence of patients with any infections were general (39.8%) and orthopaedic surgery (38.7%). Patients from those two specialties had the highest case load and proportion of HAIs (43.8% and 25.2% respectively). Neurosurgical, cardiothoracic, and vascular surgery patients reported fewer infections.

Patients with HAIs used more processes of care than those without infection. They had more than twice the odds of postoperative complications (51.0% vs 30.0%; aOR: 2.20; 95% CI: 1.98–2.45; $P < 0.001$), unplanned ICU admissions (29.3% vs 14.8%; aOR 2.18; 95% CI: 1.94–2.45; $P < 0.001$), unplanned returns to theatre (22.6% vs 10.9%; aOR 2.38; 95% CI 2.09–2.71; $P < 0.001$), and fluid balance alterations (13.3% vs 6.5%; aOR 2.00; 95% CI: 1.71–2.35; $P < 0.001$) (Table I). Fluid balance alterations were evident in all patients with infection across all specialties. No other process of care parameter exhibited the same association across all surgical specialties.

Patients with HAIs had a longer median LOS (15 days; IQR: 8–27) compared with those without infection (6 days; IQR: 2–15). Using a median regression model, both the presence of infection and the presence of fluid balance alteration were associated with significantly increased median LOS, with a greater effect seen in HAI than no infection (Table IV). HAIs added more than $22,068 (12 days × $1839) to the base cost of $4966 (2.7 days × $1839) for admitted acute care patients, and $16,551 (6 days × $1839) to those who died without infection (Appendix A) [25]. HAI combined with fluid balance alterations added a further additional hospital cost of $3678.

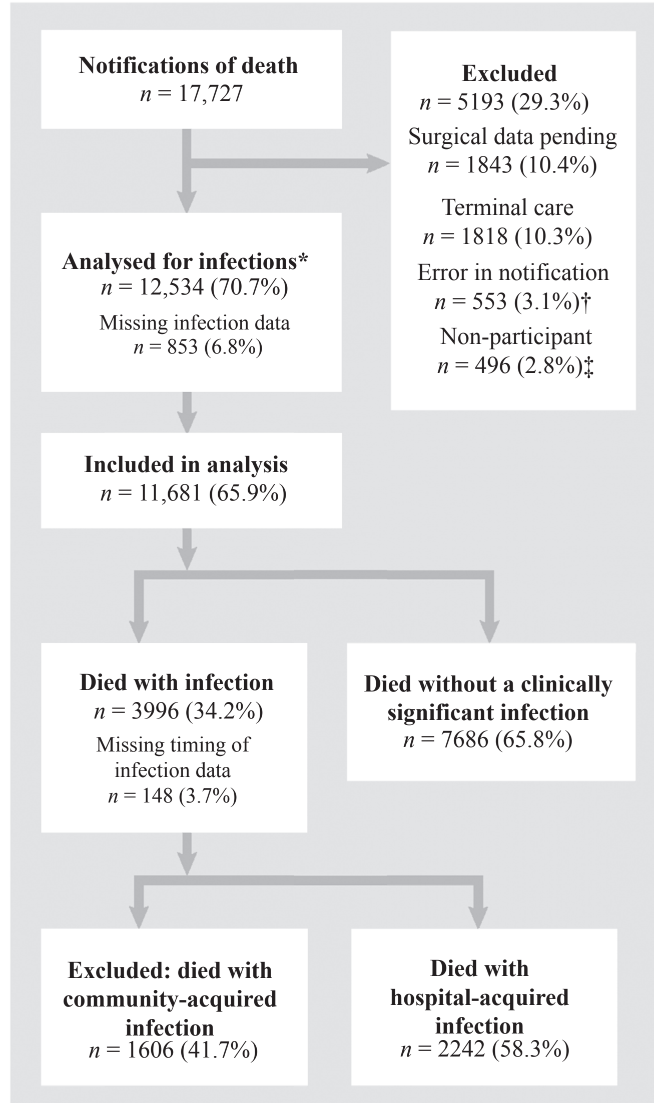

Figure 1. Study flow chart (2012–2016). * Only cases that had completed the audit process were included in analysis. † Cases not returned after two years from notification, despite regular reminders, were considered 'lost to follow-up'. ‡ Cases from non-participating surgeons.

A wide range of pathogens was noted: viruses, bacteria, fungi, and parasites. The most common type of HAI was pneumonia (732 out of 1317, 55.6%). The most prevalent bacterial pathogens (Appendix B) were *Escherichia coli* (9.1%), *Staphylococcus aureus* (7.2%), and *Pseudomonas* species (5.2%). Antibiotic therapy and resistance patterns were not captured in the dataset.

Discussion

Findings from the Australian surgical in-hospital mortality dataset demonstrate that one-fifth of surgical patients who died did so with an HAI. Patients who died with an HAI had double the LOS and triple the cost compared to those without infection. We used mortality as an index to assess the effects of infection onset on the processes of care in both private and

Table I
Association between patient demographics, clinical characteristics, processes of care, and infection status (2012–2016)

Variable	Patients without infection ($n = 7686$)	Patients with HAI ($n = 2242$)	HAI vs no infection: unadjusted OR			HAI vs no infection: adjusted OR (aOR)		
			OR	95% CI	*P*-value	aOR	95% CI	*P*-value
Malignancy								
No malignancy	3828 (67.0%)	1040 (62.2%)	1.00 (ref.)			1.00 (ref.)		
Malignancy	1459 (25.5%)	559 (33.4%)	1.41	1.25–1.59	<0.001	1.28	1.13–1.45	<0.001
Malignancy unknown	428 (7.5%)	73 (4.4%)						
Missing data	1971	570						
Comorbidities on admission								
No comorbidities	1017 (13.3%)	92 (4.1%)	1.00 (ref.)			1.00 (ref.)		
Comorbidities	6640 (86.7%)	2148 (95.9%)	3.58	2.87–4.55	<0.001	3.80	2.97–4.87	<0.001
Missing data	29	2						
Delay in surgical diagnosis								
No delay	7169 (94.1%)	2082 (93.3%)	1.00 (ref.)			1.00 (ref.)		
Delay	447 (5.9%)	150 (6.7%)	1.16	0.95–1.40	0.14	1.24	1.02–1.51	0.03
Missing data	70	10						
Operation performed in last admission								
No operation	1768 (23.0%)	263 (11.7%)	1.00 (ref.)			1.00 (ref.)		
Operation	5914 (77.0%)	1979 (88.3%)	2.25	1.96–2.59	<0.001	2.17	1.86–2.52	<0.001
Missing data	4	0						
Return to theatre								
No unplanned return	6681 (88.9%)	1709 (77.2%)	1.00 (ref.)			1.00 (ref.)		
Unplanned return	822 (10.9%)	501 (22.6%)	2.38	2.11–2.69	<0.001	2.38	2.09–2.71	<0.001
Return to theatre unknown	8 (0.1%)	4 (0.2%)						
Missing data	175	32						
Postoperative complication								
No postoperative complication	4100 (69.7%)	963 (49.0%)	1.00 (ref.)			1.00 (ref.)		
Postoperative complication	1780 (30.3%)	1004 (51.0%)	2.40	2.16–2.67	<0.001	2.20	1.98–2.45	<0.001
Missing data	1806	275						
Treated in ICU								
Not treated	3015 (39.4%)	747 (33.4%)	1.00 (ref.)					1.00 (ref.)
Treated	4641 (60.6%)	1489 (66.6%)	1.29	1.17–1.43	<0.001	1.51	1.35–1.68	<0.001
Missing data	30	6						
Unplanned ICU admission								
No unplanned admission	6364 (85.1%)	1550 (70.3%)	1.00 (ref.)			1.00 (ref.)		
Unplanned admission	1109 (14.8%)	646 (29.3%)	2.39	2.14–2.67	<0.001	2.18	1.94–2.45	<0.001
Unplanned ICU admission unknown	9 (0.1%)	9 (0.4%)						
Missing data	204	37						
Fluid balance								
No fluid balance alteration	6784 (90.8%)	1816 (82.7%)	1.00 (ref.)					1.00 (ref.)
Fluid balance alteration	484 (6.5%)	292 (13.3%)	2.25	1.93–2.63	<0.001	2.00	1.71–2.35	<0.001
Fluid balance alteration unknown	203 (2.7%)	88 (4.0%)						
Missing data	215	46						

n = number of questions answered; HAI, hospital-acquired infection; OR, odds ratio; CI, confidence interval; ICU, intensive care unit.
Missing data: denominator variation is present as the question was not answered by all.
Odds ratios were calculated using logistic regression models. Multivariate models were adjusted for age, gender, American Society of Anesthesiologists class, and comorbidities present. In all models 'no infection' was the reference group.

public hospitals across Australia. Findings are based on the opinions of Australian surgeons who collaborate with intensive care and infectious disease physicians. The most significant differences were seen in the number of postoperative complications, unplanned ICU admissions, unplanned returns to theatre and fluid balance alterations.

Our findings show that fluid balance alterations were more frequent in patients with HAIs, in keeping with published literature [7]. From the data it is not possible to determine whether the fluid balance alterations predisposed patients to develop infection or vice versa, nor if the fluid balance alterations were due to dehydration or overhydration. Recent

Table II
Surgical patients who died with hospital-acquired infection (HAI) and without infection by age group ($N = 11,497$)

Age group (years)	No infection	HAI
0–9	124 (80.0%)	30 (20.0%)
10–19	79 (89.8%)	9 (10.2%)
20–29	136 (95.1%)	7 (4.9%)
30–39	171 (85.9%)	28 (14.1%)
40–49	336 (86.8%)	51 (13.2%)
50–59	634 (81.3%)	146 (18.7%)
60–69	1090 (76.9%)	331 (23.3%)
70–79	1801 (76.7%)	545 (23.2%)
80–89	2355 (74.5%)	808 (25.5%)
90–99	907 (76.7%)	275 (23.3%)
≥100	23 (74.2%)	8 (25.8%)

studies suggest that a restricted rather than a liberal fluid management approach may be associated with improved patient outcomes [26,27].

The findings of unplanned return to theatre and the prevalence of specific organisms were similar to the literature [2,19,28]. We showed that unplanned reoperations were more frequent in the presence of infection, especially in orthopaedic and general surgery patients as previously published [19,28]. Approximately 60% of all the patients were general surgery and orthopaedic patients, accounting for the larger numbers. Despite this, HAIs were higher in these specialties than others including cardiac or plastic surgery. This may reflect gastrointestinal tract ('clean-contaminated') procedure in the general surgery patients or the ageing population of the orthopaedic patients (data not shown). The most prevalent organisms in this study reported to cause HAI were *Pseudomonas* and *S. aureus*, consistent with invasive interventions (mechanical ventilation or catheters) – essential parts of the care of the critically ill [29].

LOS was used as a marker of hospital costs [12,20]. We estimated costs associated with HAIs to be three times higher than in patients who died without infection and four times higher than the average admitted acute care patients.

Strengths of this study are that the Australian Audit of Surgical Mortality dataset are recorded directly from surgeons and the processes of care parameters provide an overview of the spectrum of care throughout a patient's hospital admission. Surgeons provide data and perspectives that cannot be gleaned from routine administrative datasets. It is a surgeon-driven process – the accuracy of which has been validated [23]. This large dataset is current to March 2016 and included both emergency and elective admissions from all surgical specialties in Australia – a high-income country setting. There are limitations to the data. Significantly, the dataset does not include patients who survived to enable comparisons, therefore limiting the generalizability of these results. Reporting bias (all surgeons self-report) is possible but it is unlikely to affect infection groups. Confounding is present as it is unknown whether one outcome stimulated another on the path to death, if infection developed after primary or secondary operation or whether the patient died with, or indeed from, an infection.

Findings of this analysis of an Australian surgical in-hospital mortality dataset are not unexpected: but they clearly indicate the size and effect of HAIs on processes of care. This may be useful when estimating the potential cost savings that can be achieved by increased efforts to prevent HAIs. This study demonstrates that HAIs are associated with increased processes of care, LOS, and hospital cost, some of which may be preventable. This applies to one-fifth of all surgical patients who died, though this is <1% of all public hospital surgical patients in Australia. This is in the context of decreasing surgical mortality rates in Australia but increasing numbers of surgical patients undergoing surgery [1]. These findings are generalizable to surgical settings in other high-income countries because of the large study size,

Table III
Surgical specialties of patients with a clinically significant infection by risk ratio of infection and proportions of HAI (2012–2016)

Surgical specialties	Patients with infection: timing not specified				Patients with HAI as proportion of their specialty	Patients with HAI as proportion of all patients with HAI ($N = 2242$)
	n/N	OR	95% CI	*P*-value		
General surgery	1899/4755 (39.8%)	Ref.[a]			983/4755 (20.7%)	983/2242 (43.8%)
Orthopaedic surgery	914/2363 (38.7%)	0.95	0.86–1.05	0.31	565/2363 (23.9%)	565/2242 (25.2%)
Neurosurgery	301/1649 (18.3%)	0.34	0.29–0.39	<0.001	225/1649 (13.6%)	225/2242 (10.0%)
Vascular surgery	266/1033 (25.8%)	0.52	0.45–0.61	<0.001	127/1033 (12.3%)	127/2242 (5.7%)
Cardiothoracic surgery	281/1000 (28.1%)	0.59	0.51–0.68	<0.001	182/1000 (18.2%)	182/2242 (8.1%)
Urology	151/410 (36.8%)	0.88	0.71–1.08	0.22	69/410 (16.8%)	69/2242 (3.1%)
Plastic surgery	89/209 (42.6%)	1.12	0.84–1.48	0.45	17/209 (18.7%)	39/2242 (1.7%)
Otolaryngology head and neck surgery	59/132 (44.7%)	1.22	0.86–1.72	0.27	31/132 (23.5%)	31/2242 (1.4%)
Paediatric surgery	18/60 (30.0%)	0.64	0.37–1.12	0.12	13/60 (21.7%)	13/2242 (<1.0%)
Obstetrics and gynaecology surgery	14/41 (34.1%)	0.78	0.41–1.49	0.45	7/41 (17.1%)	7/2242 (<1.0%)
Oral/maxillofacial surgery	2/5 (40.0%)	1.00	0.17–6.01	1.00	N/A	N/A
Ophthalmology	1/4 (25.0%)	0.50	0.05–4.82	0.55	1/4 (25.0%)	1/2242 (<1.0%)
Other	5/6 (83.3%)	7.51	0.88–64.42	0.07	N/A	N/A

HAI, hospital-acquired infection; OR, odds ratio; CI, confidence interval; N/A, numbers too low for analysis.
'Other' includes: intensive care unit, medical oncology, physicians, consultant physician.
[a] General surgery as the largest specialty is used as the reference for risk ratios.

Table IV
Effect of time of hospital-acquired infection and fluid balance alteration on length of stay in patients who died (2012—2016)

Infection status	Fluid balance alteration	*N*	Length of stay (days)	Unadjusted median difference (uMD)			Adjusted median difference (aMD)		
			Median (IQR)	uMD	95% CI	*P*-value	aMD	95% CI	*P*-value
No infections	No fluid balance alteration	7425	6 (2—15)	Ref.			Ref.		
	Fluid balance alteration	543	9 (4—20)	3.0	2.0—4.0	<0.001	2.7	1.6—3.9	<0.001
Hospital-acquired infections	No fluid balance alteration	1816	15 (8—27)	9.0	8.4—9.6	<0.001	8.2	7.5—11.4	<0.001
	Fluid balance alteration	292	17 (9—32)	11.0	9.6—12.4	<0.001	9.8	8.3—11.4	<0.001

IQR, interquartile range; CI, confidence interval.

inclusion of all surgical specialties, inclusion of all operations and the high reporting rate [22].

In conclusion, one-fifth of surgical patients who died in hospital died with an HAI present. Surgical patients with an HAI were associated with more intensive management than those who died without infection. Further studies need to measure the same processes of care in surgical patients who survive to fully understand the impact of infections in surgical patients.

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Conflict of interest statement

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jhin.2017.09.001.

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