Associations of hospital characteristics with nosocomial pneumonia after cardiac surgery can impact on standardized infection rates

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SUMMARY

To identify hospital-level factors associated with post-cardiac surgical pneumonia for assessing their impact on standardized infection rates (SIRs), we studied 43 691 patients in a cardiac surgery registry (2001–2011) in 16 hospitals. In a logistic regression model for pneumonia following cardiac surgery, associations with hospital characteristics were quantified with adjustment for patient characteristics while allowing for clustering of patients by hospital. Pneumonia rates varied from 0·7% to 12·4% across hospitals. Seventy percent of variability in the pneumonia rate was attributable to differences in hospitals in their long-term rates with the remainder attributable to within-hospital differences in rates over time. After adjusting for patient characteristics, the pneumonia rate was found to be higher in hospitals with more registered nurses (RNs)/100 intensive-care unit (ICU) admissions [adjusted odds ratio (aOR) 1·2, $P = 0·006$] and more RNs/available ICU beds (aOR 1·4, $P < 0·001$). Other hospital characteristics had no significant association with pneumonia. SIRs calculated on the basis of patient characteristics alone differed substantially from the same rates calculated on the basis of patient characteristics and the hospital characteristic of RNs/100 ICU admissions. Since SIRs using patient case-mix information are important for comparing rates between hospitals, the additional allowance for hospital characteristics can impact significantly on how hospitals compare.

Key words: Pneumonia.

INTRODUCTION

Reducing complications after cardiac surgery should improve patient outcomes and save the health system considerable expense. Pneumonia incidence in patients who have undergone heart surgery may reach 20%, and carries a strong association with subsequent mortality

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[1, 2]. Age, emergency surgery, chronic obstructive pulmonary disease (COPD), and smoking have been identified as patient-related factors strongly associated with the occurrence of pneumonia after cardiac surgery [2–5].

It is clear that infection rates vary across hospitals, but whether hospital-level characteristics are associated with pneumonia risk following cardiac surgery remains unclear. This may be due to differences in measurement of nurse staffing [e.g. registered nurse (RN) hours or RN proportion], sources of data on hospital-level characteristics, different research designs (e.g. cross-sectional *vs.* longitudinal), different statistical approaches to data analysis, or different patient samples (medical patients, surgical patients, mixed medical and surgical patients) [6–17]. However, some hospital-level variables remain entirely unexplored despite much literature suggesting that certain hospital characteristics relate to poorer patient outcomes in general.

In this context, we sought to understand better whether hospital characteristics such as hospital volume, number of hospital beds, RN staffing, standards for airway management, standards for central line insertion, and rounds with an infectious disease specialist are associated with pneumonia following cardiac surgery. Further we aimed to assess whether such associations, if they exist, could impact on standardized infection rates (SIRs) and hence alter hospital comparisons.

METHODS

Data source and study population

This study used information from the Australian and New Zealand Society of Cardiac and Thoracic Surgeons (ANZSCTS) registry of cardiac surgery procedures from 2001 to 2011 [18]. All patients were treated post-operatively in an intensive-care unit (ICU) for at least 1 h. This project was undertaken following approval from the ANZSCTS Research Committee, which governs access to data from the registry. Ethical approval for the use of de-identified registry data for secondary research purposes had previously been provided by each participating institution's ethics review committee.

The Australian and New Zealand Intensive Care Society–Centre for Outcome and Resource Evaluation (ANZICS-CORE) has collected audit and analysis data on performance indicators of Australian and New Zealand ICUs since 1992. ANZICS-CORE provided hospital-level characteristics from 2001 to 2011 annual surveys after approval from each ICU director

of participating hospitals in the ANZSTCS registry [19]. For the hospital-level variables related to measures of ICU staffing, missing values were replaced by one of the following methods as appropriate: (i) the average of 1 year before and 1 year after the year with missing information, (ii) the average of the two preceding annual values, (iii) the average of the available information.

For the hospital-level variables related to measures of ICU safety and quality, the 2007 values were used as these represented approximately a mid-point in study duration given the later entry of some of the hospitals to the registry.

Outcome measures

Data on three relevant post-operative syndromes within 30 days of surgery were collected in the ANZSCTS registry:

(1) *Pneumonia*. Diagnosed by one of the following: positive non-quantitative cultures of sputum or trans-tracheal aspirate with a recognized pathogen and clinical and radiological features consistent with pneumonia with onset after surgery.
(2) *Ventilation*. Post-operative pulmonary insufficiency requiring ventilatory support – including (but not limited to) causes such as acute respiratory distress syndrome (ARDS) and pulmonary oedema – for a total period of >24 h.
(3) *Re-intubation*. Was re-intubation required for any reason during hospitalization?

Due to the lack of a clear gold standard, three definitions of pneumonia were used based on the three syndromes as follows: (i) pneumonia, (ii) pneumonia and ventilation, and (iii) pneumonia and ventilation and re-intubation. Definition (i) 'pneumonia', was treated as the main outcome in subsequent analyses but results are also presented for definitions (ii) and (iii).

Patient-level variables

An existing prediction model for nosocomial pneumonia after cardiac surgery [20] which was validated for use in the Australian setting [21] was used to adjust for patient-level variables (Table 1). Using this defined prediction tool avoided the subjectivity involved in selecting variables for inclusion in our analysis. The prediction tool combined information on underweight status [body mass index (BMI) <18·5, where BMI was calculated as weight (kg) divided by height (m^2)], smoking history defined as having smoked cigarettes

Table 1. *Patient-level characteristics*

Risk factor	All patients, (N = 43 691)		Patients with pneumonia (N = 2229)		Patients without pneumonia (N = 41 462)	
	n	%	n	%	n	%
Underweight, BMI <18·5	543	1·2	44	2·0	499	1·2
Smoking history	27 122	62·1	1556	69·8	25 566	61·7
COPD	1648	3·8	132	5·9	1516	3·7
CCS class ⩾3	14 545	33·3	818	36·7	13 727	33·1
Creatinine level >1·2 mg/dl	10 867	24·9	773	34·7	10 094	24·3
Emergent surgery	2071	4·7	278	12·5	1793	4·3
Intraoperative blood transfusion	19 144	43·8	1556	69·8	17 588	42·4
PTCA during hospitalization	406	0·9	36	1·6	370	0·9
Mechanical ventilation >1 day	5664	13·0	1015	45·5	4649	11·2

BMI, Body mass index; COPD, chronic obstructive pulmonary disease; CCS class, Canadian cardiovascular society classification of angina; PTCA, percutaneous transluminal coronary angioplasty.
BMI calculated as weight (kg) divided by height (m^2).

during the year before hospital admission, COPD, Canadian Cardiovascular Society classification of angina [22] (CCS) class ⩾3, serum creatinine level (the most recent measurement) >1·2 mg/dl (106·1 mmol/ml), surgery urgency categorized as non-emergency and emergency, intraoperative blood transfusion, percutaneous transluminal coronary angioplasty (PTCA) during hospitalization and mechanical ventilation >1 day.

Hospital-level variables

Existing literature on hospital-level associations with development of pneumonia after cardiac surgery indicated potential importance of measures of hospital size, measures of ICU patient load and measures of ICU safety and quality [10, 13–17].

Measures of hospital size

Hospital volume was calculated for each hospital from the ANZSCTS registry as the median of the hospital's annual number of cardiac surgeries across 2001–2011. All subsequent hospital-level factors were as reported in the ANZICS-CORE annual survey. Hospital bed number was the total number of beds in each hospital. This is self-reported by hospitals to the ANZICS Critical Care Resources (CCR) registry and represents the number of in-patient hospital beds (excluding beds for psychiatry and day case procedures).

Measures of ICU staffing

RNs/100 ICU admissions was defined as 100 times the number of RNs full-time equivalent staff divided by total ICU admissions. RNs/available ICU bed was defined as the number of RNs full-time equivalent staff divided by total available ICU beds (including cardiothoracic ICU beds). An available ICU bed is a bed in use or immediately available, which has advanced life support capability and is fully staffed and funded.

Measure of ICU safety and quality

As part of the annual ANZICS-CORE survey, hospitals are asked if they have processes and standards for accreditation and management of various procedures and processes within the ICU. Markers of hospital safety and quality that were reported included those that met standards for airway management, met standards for central line insertion, and conducted routine rounds with an infectious disease specialist; all were dichotomous variables (yes/no).

Statistical analysis

An updated version of an existing prediction model for nosocomial pneumonia after cardiac surgery [20] was applied to the ANZSCTS dataset [21]. The updated version of the model coefficients yielded reasonable predictive ability as indicated by the receiver-operating characteristic curve (AUC) = 0·71, and was well calibrated [21].
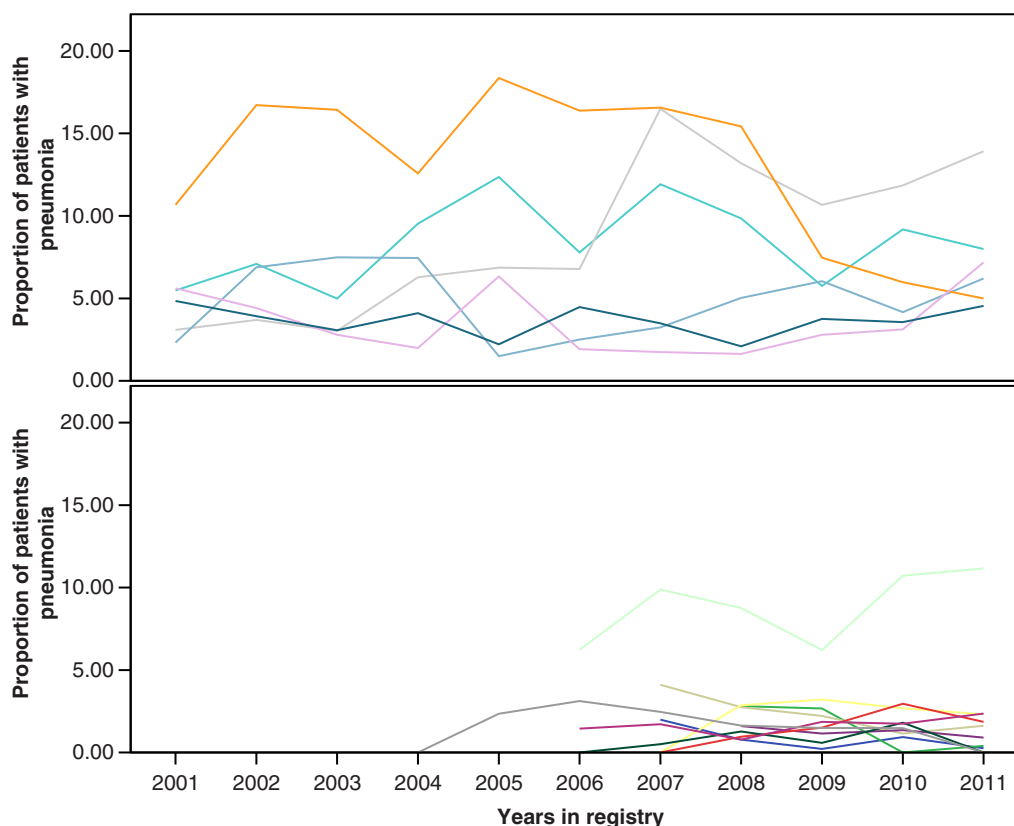
Fig. 1. The nosocomial pneumonia rate (%) in 16 hospitals between 2001 and 2011. Top panel shows six hospitals present in the registry from its inception, 2001. Bottom panel shows 10 hospitals that joined the registry in later years.

Intra-class correlation (ICC) was used to measure the total variability in pneumonia incidence between hospitals compared to within hospitals over the study period. To address potential within-hospital correlation, a logistic regression model using generalized estimating equations (GEEs) with an exchangeable working correlation structure was fitted to nosocomial pneumonia. This allowed for within-hospital clustering of patient-level responses [23]. In the GEE approach, the coefficient for each hospital-level variable is an estimated population-averaged relationship between the variable and patient-level outcome, adjusting for any patient-level characteristics included in the model.

SIRs were calculated as the pneumonia rate observed in the hospital of interest (i.e. observed) divided by the pneumonia rate in a standard population (i.e. expected) and were used to compare the pneumonia rates in hospitals. Hospitals with SIR <1 (number of observed pneumonia cases following cardiac surgery is less than predicted) are 'better than expected' and hospitals with SIR >1 are 'worse than expected'.

Statistical significance was defined as $P < 0.05$ with no adjustment for multiple hypothesis testing. All statistical analyses were performed using Stata v. 11 (StataCorp., USA).

RESULTS

In total, 54 217 cardiac operations were performed in 25 hospitals during the 11-year study period. Nine hospitals (6540 patients) were excluded either because they were in the registry <1 year (seven hospitals), did not have adult patients (one hospital) or because they declined to have their ANZICS-CORE hospital-level data released (one hospital). In the remaining 16 hospitals, 3986 (8·4%) patients were excluded due to missing data for outcome, patient-level, or hospital-level variables.

Characteristics of patients and hospitals

In the remaining 43 691 patients the mean ± standard deviation (s.d.) age was 66 ± 13 years. Nosocomial pneumonia was reported in 5·1% (n = 2229), varying from 0·7% to 12·4% across hospitals and overall from 3·7% to 6·9% between 2001 and 2011 (Fig. 1).

For patients with pneumonia, 30-day mortality was 7·1% and mean duration of ventilation was 104 ± 222 h, compared to a 30-day mortality rate of 2·1% and mean 21 ± 60 h ventilation for patients who did not have pneumonia.

Table 1 summarizes the characteristics of the study population.

Hospital volume was on average 428 ± 101 (range 183–573) surgeries, number of hospital beds averaged 448 ± 155 (range 118–860) beds and the mean number of full-time equivalent RNs was 102 ± 50 (range 9–223). In 29% of hospitals, rounds with an infectious disease specialist were provided; 44% and 38% of hospitals met standards for airway management and central line insertion, respectively.

Between-hospital variability in pneumonia incidence

An ICC of 0·70 [95% confidence interval (CI) 0·5–0·9] suggests that 70% of the total variability in pneumonia incidence is explained by differences between hospitals, with the remainder attributable to within-hospital differences over time. In other words, the changes in pneumonia incidence within a hospital over the 10 years were minor in comparison to the differences between hospitals in their respective long-term pneumonia incidence rates.

In unadjusted analysis, the ratio of RNs/100 ICU admissions [odds ratio (OR) 1·2, 95% CI 1·1–1·3, $P < 0.001$] and the ratio of RNs/available ICU bed (OR 1·5, 95% CI 1·2–1·7, $P < 0.001$) were associated with pneumonia incidence. Indicating increased incidence rates being accompanied by higher nurse staffing levels/100 ICU admissions and per available ICU bed, this relationship is illustrated in Figure 2.

The results of univariate analysis, and multivariate analysis after adjusting for patient-level characteristics, are described in Table 2. Other hospital-level characteristics including hospital volume, number of hospital beds, standards for airway management, standards for central line insertion, and rounds with an infectious disease specialist did not exhibit any significant association with pneumonia incidence.

After adjusting for patient-level variables, the risk of pneumonia was still higher in hospitals with more RNs/100 ICU admissions (adjusted OR 1·2, 95% CI 1·0–1·3, $P = 0.006$) and more RNs/available ICU bed (adjusted OR 1·4, 95% CI 1·2–1·7, $P < 0.001$). The two other definitions of nosocomial pneumonia gave results that were similar to those already presented with no changes in conclusions about hospital-level risk factors. (Table 2)

Standardized infection rates

Figure 3 shows the change to each hospital's ratio of observed to predicted pneumonia when using a model with patient-level risk factors only to a model that also includes RNs/100 ICU admissions (hospital-level risk factor). Assessment of whether a hospital's infection rate is as expected alters substantially when 'as expected' takes a hospital-level covariate into account. The hospital-level characteristic holds considerable sway in explaining between-hospital variability in infection rates and hence in explaining SIRs that deviate from SIR = 1. The effect is to bring the majority of hospital SIRs towards SIR = 1.

DISCUSSION

This study found some evidence that hospital characteristics are related to variations in the incidence of nosocomial pneumonia after cardiac surgery and that accounting for these characteristics can have a major impact on comparisons of hospital performance via standardized pneumonia rates.

Across the 43 000 patients from 16 Australian hospitals in this study, pneumonia incidence rates varied considerably. The development of pneumonia after cardiac surgery was found to be associated with two hospital characteristics although the direction of the association was counterintuitive; pneumonia risk was found to be positively associated with the number of RNs/100 ICU admissions and per available ICU bed. This association was evident in both crude and adjusted analyses. It is possible that higher staffing levels are a surrogate marker for an unmeasured confounder (e.g. higher risk patients not identified by other measures), or that increasing rates of postoperative pneumonia require higher levels of nurse staffing in the ICU.

Given that pneumonia is a nurse-sensitive outcome [14, 24], ICU nurses have a key role in preventing pneumonia in most patients [24]. Our study found an association between pneumonia and one of the nurse staffing measures but not with another. This can be added to the inconsistent evidence of association between nursing ratios and pneumonia [25] In European settings, a Belgian study [13] showed no association between nurse staffing and pneumonia, but Swiss [26] and British [27] studies found an inverse
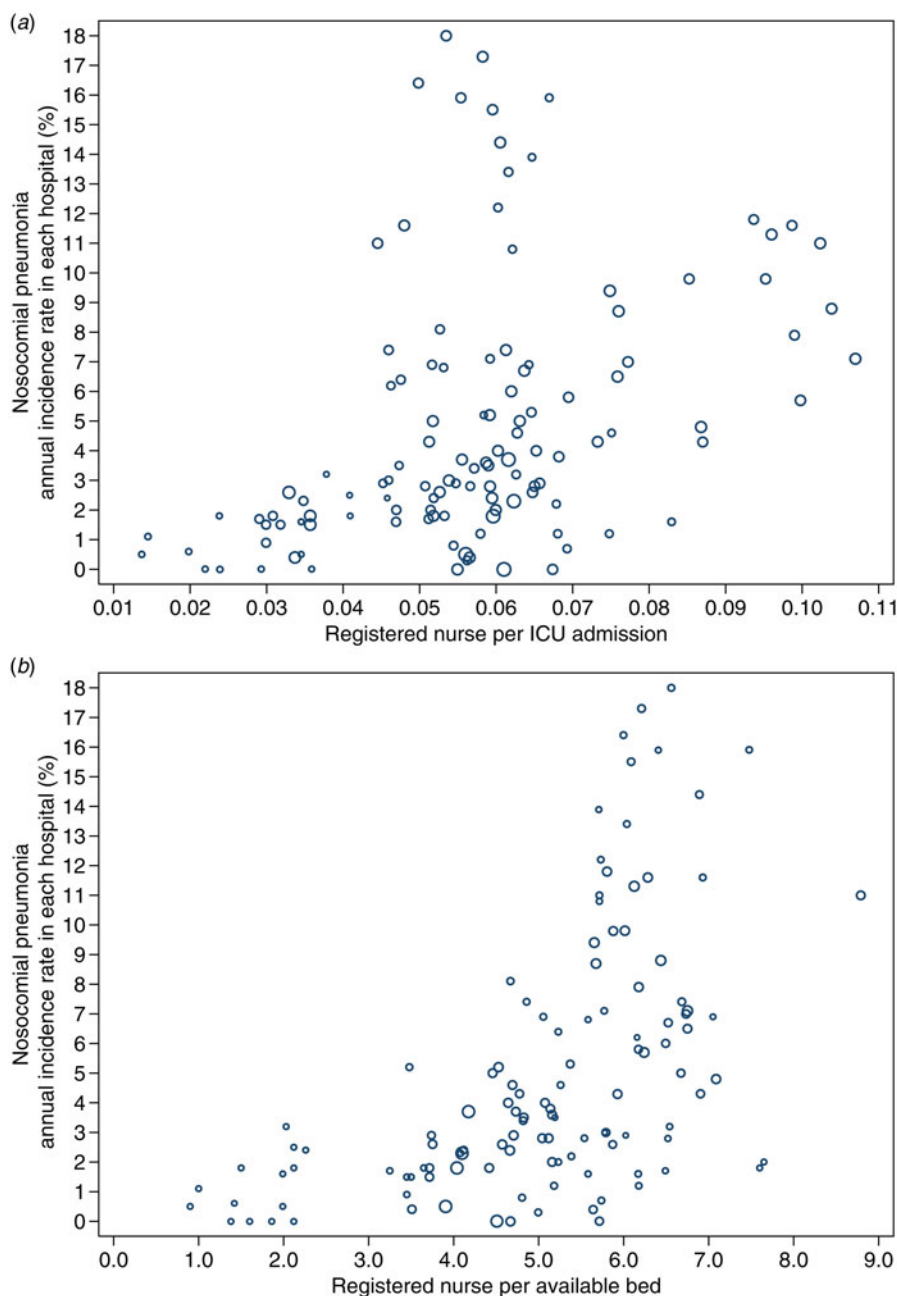
Fig. 2. The relationship between nosocomial pneumonia annual cumulative incidence rate (%) and number of registered nurses/ICU admissions and per available intensive-care unit (ICU) bed in the corresponding year. The area of each circle is proportional to hospital size as measured by the hospital's (a) total number of ICU admission and (b) total number of available beds in the given year, respectively.

relationship. In American settings [6, 7, 28] an inverse relationship between nurse staffing and pneumonia was found in California hospitals but not in New York hospitals. This relationship was reported in surgical and medical units [8]. While an inverse relationship between the number of RNs/patient days and pneumonia has been found after surgery but not after invasive vascular procedures [29], this relationship

was not confirmed in other studies [9, 11, 30]. Our finding of a positive association differs from most other studies. It is likely that a high nursing:patient ratio is a surrogate marker for ICUs that treat more complex patients. It may also represent an effect rather than a cause, and indicates the stress on resources resulting from higher rates of this complication over the long term.

Table 2. *The results of univariate and multivariate analysis after adjusting for patient-level characteristics*

Hospital characteristics	Univariate analysis			Multivariate analysis adjusting for patient-level risk factors		
	OR	(95% CI)	*P*	OR	(95% CI)	*P*
Outcome: definition (i) (*n* = 2229 cases)						
Hospital volume (/100 surgeries)	0·9	(0·6–1·3)	0·5	0·9	(0·7–1·3)	0·6
Hospital beds (/100 beds)	1·1	(0·9–1·3)	0·4	1·1	(0·9–1·3)	0·4
RNs/100 ICU admissions	1·2	(1·1–1·3)	<0·001	1·2	(1·0–1·3)	0·006
RNs/available ICU bed	1·5	(1·2–1·7)	<0·001	1·4	(1·2–1·7)	<0·001
Standards for airway management (yes)	1·2	(0·5–2·7)	0·6	1·2	(0·6–2·4)	0·6
Standards for central line insertion (yes)	1·6	(0·8–3·4)	0·2	1·7	(0·9–3·4)	0·1
Rounds with infectious disease specialist (yes)	1·0	(0·4–2·4)	0·9	1·1	(0·5–2·2)	0·8
Outcome: definition (ii) (*n* = 1176 cases)						
Hospital volume (/100surgeries)	1·0	(0·7–1·4)	0·8	1·0	(0·7–1·4)	0·9
Hospital beds (/100 beds)	1·0	(0·8–1·2)	0·9	1·0	(0·8–1·2)	0·8
RNs/100 ICU admissions	1·2	(1·1–1·3)	<0·001	1·1	(1·0–1·2)	0·02
RNs/available ICU bed	1·4	(1·2–1·6)	<0·001	1·3	(1·1–1·6)	0·001
Standards for airway management (yes)	1·3	(0·5–3·2)	0·5	1·3	(0·6–2·8)	0·4
Standards for central line insertion (yes)	1·5	(0·6–3·6)	0·3	1·7	(0·8–3·3)	0·1
Rounds with infectious disease specialist (yes)	1·1	(0·4–3·0)	0·9	1·1	(0·5–2·6)	0·8
Outcome: definition (iii) (*n* = 501 cases)						
Hospital volume (/100 surgeries)	1·0	(0·8–1·3)	0·9	1·1	(0·8–1·3)	0·6
Hospital beds (/100 beds)	0·9	(0·8–1·1)	0·6	0·9	(0·8–1·1)	0·6
RNs/100 ICU admissions	1·2	(1·1–1·2)	<0·001	1·1	(1·0–1·1)	0·008
RNs/available ICU bed	1·3	(1·2–1·5)	<0·001	1·2	(1·1–1·4)	<0·001
Standards for airway management (yes)	1·2	(0·6–2·6)	0·6	1·1	(0·7–2·2)	0·6
Standards for central line insertion (yes)	1·1	(0·5–2·6)	0·8	1·3	(0·8–2·2)	0·3
Rounds with infectious disease specialist (yes)	1·1	(0·5–2·4)	0·9	1·1	(0·6–2·1)	0·6

OR, Odds ratio; CI, confidence interval; RN, registered nurse; ICU, intensive care unit;
Definition (i): Pneumonia; definition (ii): pneumonia and ventilation; definition (iii): pneumonia and ventilation and re-intubation. Pneumonia diagnosed by one of the following: positive non-quantitative cultures of sputum or trans-tracheal aspirate with a recognized pathogen and clinical and radiological features consistent with pneumonia with onset after surgery. Ventilation: Post-operative pulmonary insufficiency requiring ventilatory support – including (but not limited to) causes such as acute respiratory distress syndrome (ARDS) and pulmonary oedema – for a total period of longer than 24 h. Re-intubation: Was re-intubation required for any reason during hospitalization?

The SIR is a patient safety metric developed by the Centres for Disease Control and Prevention for comparing outcomes across health providers while adjusting for differences in outcome risk [31]. Our results demonstrate that consideration of hospital-level associations with outcome is important when calculating standardized pneumonia rates following cardiac surgery. Additional allowance for a hospital-level association over and above patient characteristics tended to bring SIRs towards 'as expected' performance. This powerful impact calls for incorporation of hospital-level associations, although in our analysis the counterintuitive nature of the association is somewhat problematic, as discussed above. Nevertheless the results are a marked illustration of the potential importance of hospital characteristics in the calculation of SIRs.

Our study has several limitations. Of 26 public and 33 private Australian hospitals that undertake cardiac surgery, 20 public and eight private hospitals are enrolled and participate in the ANZSCTS Cardiac Surgery Database programme. For this study we studied a subset of 13 public and three private hospitals from the registry which may not be representative of all relevant Australian hospitals, which may impact the generalizability of findings. Additionally, even this many hospitals may still have been insufficient to detect associations for binary hospital-level factors such as meeting standards for airway management and central line insertion, and rounds with an infectious disease specialist. Although guidelines for difficult airway management and for central line insertion have been produced by professional societies
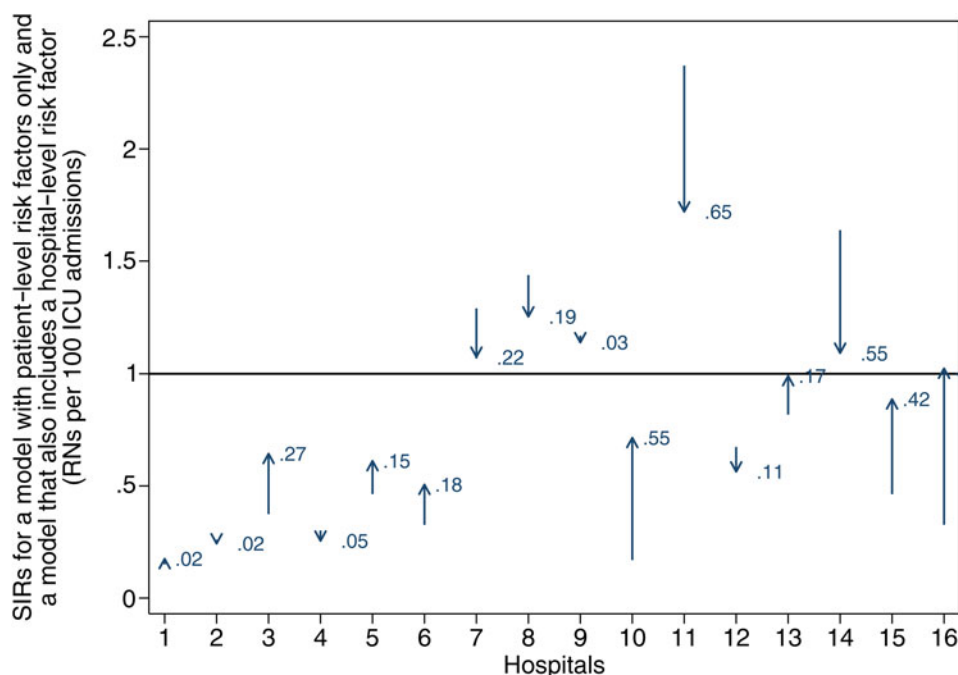
Fig. 3. Standardized infection rates from the ratio of observed to predicted pneumonia for a model with patient-level risk factors only (tail of arrows) and a model that also includes RNs/100 intensive-care unit (ICU) admissions as a hospital-level risk factor (head of arrows) in 16 hospitals. Examples for comparing the hospital standardized infection rates (SIRs): The relative change for hospital 10 is 0·55, which means the SIR increased by 55% after applying the model including RNs/100 ICU admissions as a hospital-level risk factor. The relative change for hospital 11 is −0·65, which means the SIR decreased by 65% after applying the model including RNs/100 ICU admissions as a hospital-level risk factor.

(ANZCA airway guideline and Commission/ANZICS guideline for CVC) and some states (NSW central line guideline), their local implementation and potential modification is at the discretion of professionals within the hospital or ICU [32–34]. The ANZICS-CORE annual survey asks if hospitals have a 'standard or policy' for the relevant procedure. Information from the ANZICS-CORE Annual Survey 2007 was predominantly used and some of this hospital-level information may have changed over time. Further, other hospital-level factors of potential importance such as bed occupancy and staffing/1000 patient days were not available.

The North American risk prediction model was an objective way of allowing for patient-level risk factors, avoiding the dangers of selectively adjusting for patient-level risk factors, but may leave residual confounding, with no adjustment made for some patient-level risks. If patient-level risk factors vary by hospital their effects can then be inadvertently linked with hospital-level risk factors.

The reported pneumonia incidence after cardiac surgery is significantly influenced by the definition used.

An epidemiological definition of nosocomial pneumonia is notoriously difficult, as has been recognized in the recent partial abandonment by the National Healthcare Safety Network (NHSN) of 'ventilator-associated pneumonia' in favour of the more heterogeneous 'ventilator-associated condition' [35]. In this study, our definitions were constrained by the information collected by the registry and the definition of 'pneumonia and ventilation' most closely corresponds to 'possible ventilator-associated pneumonia' in the new NHSN definitions (not available at the time of our study) [36]. Although the use of quantitative cultures may improve the specificity of the diagnosis of pneumonia, these are not widely available in Australian hospitals. Notably, the presence of pneumonia, as defined in our study, was associated with a significant increase in mortality risk. However, the reliability of this definition is uncertain and we cannot exclude the possibility that differences in sensitivity and specificity between observers may be partially responsible for the observed variation in pneumonia incidence between hospitals.

In this study we examined the relationship between hospital-level characteristics and pneumonia following

cardiac surgery in the Australian context. We found that pneumonia incidence varies considerably between hospitals. We found limited evidence that hospital factors hold associations with pneumonia incidence rates following cardiac surgery. However, the impact of the hospital-level associations on SIR can be marked.

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DECLARATION OF INTEREST

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