

Central line-associated bloodstream infections in Australian ICUs: evaluating modifiable and non-modifiable risks in Victorian healthcare facilities

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SUMMARY

Central line-associated bloodstream infections (CLABSIs) in intensive care units (ICUs) result in poor clinical outcomes and increased costs. Although frequently regarded as preventable, infection risk may be influenced by non-modifiable factors. The objectives of this study were to evaluate organisational factors associated with CLABSI in Victorian ICUs to determine the nature and relative contribution of modifiable and non-modifiable risk factors. Data captured by the Australian and New Zealand Intensive Care Society regarding ICU-admitted patients and resources were linked to CLABSI surveillance data collated by the Victorian Healthcare Associated Infection Surveillance System between 1 January 2010 and 31 December 2013. Accepted CLABSI surveillance methods were applied and hospital/patient characteristics were classified as ‘modifiable’ and ‘non-modifiable’, enabling longitudinal Poisson regression modelling of CLABSI risk. In total, 26 ICUs were studied. Annual CLABSI rates were 1·72, 1·37, 1·00 and 0·93/1000 CVC days for 2010–2013. Of non-modifiable factors, the number of non-invasively ventilated patients standardised to total ICU bed days was found to be independently associated with infection (RR 1·07; 95% CI 1·01–1·13; $P = 0\cdot030$). Modelling of modifiable risk factors demonstrated the existence of a policy for mandatory ultrasound guidance for central venous catheter (CVC) localisation (RR 0·51; 95% CI 0·37–0·70; $P < 0\cdot001$) and increased number of sessional specialist full-time equivalents (RR 0·52; 95% CI 0·29–0·93; $P = 0\cdot027$) to be independently associated with protection against infection. Modifiable factors associated with reduced CLABSI risk include ultrasound guidance for CVC localisation and increased availability of sessional medical specialists.

Key words: Central line-associated bloodstream infection (CLABSI), preventable, risk, ultrasound-guidance.

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INTRODUCTION

Central line-associated bloodstream infections (CLABSIs) in intensive care units (ICUs) result in increased morbidity, prolonged hospitalisation and greater healthcare expenditure [1, 2]. CLABSI events are frequently regarded as preventable, leading to public reporting of infection rates [3], 'zero tolerance' in many programs [4], and inclusion in pay-for-performance healthcare funding schemes [5]. These healthcare-associated infections are therefore considered key quality indicators.

Over the last decade, the impact of multi-modal interventions (bundles of care) for reduction in CLABSI rates in ICUs has been evaluated [6, 7]. The underlying premise is that modifiable risk factors for infection can be mitigated by implementation of effective quality improvement programs. However, risks for infection may also be influenced by non-modifiable factors within a healthcare facility (such as case-mix) [4, 8], and it has been estimated that up to 35% of CLABSI events may not be preventable [9, 10]. This means that even with quality improvement efforts, a zero CLABSI rate may not be achievable or sustainable [11]. Few have evaluated the characteristics of healthcare facilities to determine the nature of non-modifiable factors contributing to risk of infection [4, 11, 12].

CLABSI events in Victorian ICUs are monitored using uniform surveillance methods consistent with the Centers for Disease Control/National Healthcare Safety Network (CDC/NHSN) [13]. Annual review of ICU resources and services, including factors potentially associated with infection risk, is performed by the Australian and New Zealand Intensive Care Society (ANZICS) Centre for Outcome and Resource Evaluation (CORE) [14]. Since 2012, ANZICS CORE has also collated and reported annual ICU CLABSI rates throughout Australia and New Zealand. The objectives of this study were to use these datasets to evaluate organisational factors associated with CLABSIs in Victorian ICUs to determine the nature and relative contribution of modifiable and non-modifiable risk factors.

METHODS

The Victorian Healthcare Associated Infection Surveillance System (VICNISS) Coordinating Centre was established for the purpose of monitoring a range of healthcare-associated infection outcomes

and relevant processes in Victorian hospitals, including CLABSI [15]. The CLABSI surveillance module is based upon methods employed by the CDC/NHSN [16, 17].

All Australian and New Zealand ICUs are invited to participate in the ANZICS CORE registry benchmarking programs and software is provided to units to assist in data collection. Patient level data on diagnosis, severity of illness and outcomes are submitted quarterly to the ANZICS Adult Patient Database. In addition, ICUs are surveyed annually to obtain information on resources (e.g. ICU bed numbers), processes of care (e.g. compliance with accredited care standards) and staffing levels (e.g. number of nursing staff), which is collected by the ANZICS Critical Care Resources Registry. These data support research on resourcing and planning, disease trends and effectiveness of quality improvement programs [14].

Participating hospitals

Victorian ICUs provide services for mixed medical and surgical patient populations rather than as single-specialty units [18]. Hospitals participating in both the VICNISS program and ANZICS CORE activities for adult ICUs between 1 January 2010 and 31 December 2013 were included in this analysis, excluding those with paediatric and neonatal ICUs.

Definitions

For the purposes of surveillance, a central venous catheter (CVC) was defined as an intravascular catheter terminating at or close to the heart or in one of the great vessels, which was used for infusion, withdrawal of blood, or haemodynamic monitoring. Consistent with CDC/NHSN criteria, CLABSI was defined when (i) a patient had a recognised pathogen cultured from one or more blood cultures, and the organism was not related to infection at another site, or (ii) a patient had one or more of fever ($>38^{\circ}\text{C}$), chills or hypotension, a common commensal organism was cultured from two or more blood cultures drawn on separate occasions, and positive results were not related to infection at another site [17]. CLABSI rates were reported using the denominator of CVC days.

Captured hospital-level characteristics were defined as 'modifiable' and 'non-modifiable' risk factors by a consensus involving three clinicians (LW, AC and DP). Modifiable factors were regarded as reversible

Table 1. Patient and hospital-level characteristics potentially associated with infection risk: classification of modifiable and non-modifiable factors

Modifiable factors	Non-modifiable factors
<ul style="list-style-type: none"> ● Any infective diagnosis ● Ventilated in first 24 h ● Policy of mandatory ultrasound guidance for CVC localisation ● Number of registered nurse FTE ● Total invasively ventilated hours ● Total non-invasively ventilated hours ● Number of salaried specialists FTE ● Number of sessional specialists FTE ● Total number of non-intensive care specialists FTE 	<ul style="list-style-type: none"> ● Annual number of patients with known mortality ● Age ● APACHE III score ● Number of invasive ventilation ● Number of non-invasively ventilated patients

CVC, central venous catheter; FTE, full-time equivalent; APACHE, acute physiology and chronic health evaluation

and amenable to change according to allocated financial or human resources. Classification of hospital- and patient-level characteristics is summarised in Table 1.

Data collection and validation

Data regarding CLABSI events were collected and submitted quarterly by infection prevention staff affiliated with participating healthcare facilities. All staff were trained regarding case-definitions and standardized data collection by VICNISS Coordinating Centre staff. All data were submitted electronically via a standardised data collection tool. As an internal validation measure, electronic submission precluded lodgement of incomplete or inconsistent data. Prospective monitoring was performed, with contribution from patient records and microbiology reports.

Data linkage

Data from the VICNISS surveillance program and ANZICS datasets were linked at the level of the ICU site using a unique ICU identification number.

Statistical analyses

Categorical variables were summarised using frequency and percentage. Continuous variables were summarised using mean and standard deviation (s.d.) or median and inter-quartile range (IQR), as appropriate. Correlates of CLABSI risk across the observation period were modelled using unadjusted and adjusted longitudinal Poisson regression. CLABSI counts were tested for over-dispersion. Effect sizes were quantified as relative risk (RR) while cumulative period central

line days were specified as the offset exposure variable. A goodness-of-fit χ^2 test was used to assess overall model fit. Modelling was performed across all factor types and sub-group analyses were then performed for sets of pre-specified modifiable and non-modifiable covariates. A test of interaction was used to test for sub-group effects. For all analysis, $P < 0.05$ was considered significant. All analyses were undertaken using Stata version 14 (StataCorp, College Station, Texas).

Ethics

The study was reviewed and approved by the Alfred Health Human Research Ethics Committee. No patient-identifying data were captured for the purposes of the study, and all hospital-level data were de-identified.

RESULTS

During the study period, a total of 37 public and private hospitals were resourced to provide adult ICU care in Victoria. Of these, 26 hospitals (70.3% of total), including 20 public and six private facilities, participated in both the VICNISS program and ANZICS CORE activities and were therefore eligible for inclusion. All studied ICUs had competency standards for CVC insertion, ward rounds with an infectious diseases specialist or microbiologist, rounds with a pharmacist, an antimicrobial stewardship program, infection prevention policy, generation of regular antibiograms specific to the ICU and a critical incident monitoring program.

The aggregate annual CLABSI rate for studied ICUs was 1.72 (95% confidence interval (CI) 1.40–2.08)/1000 CVC days in 2010, 1.37 (95% CI 1.08–1.70)/1000 CVC

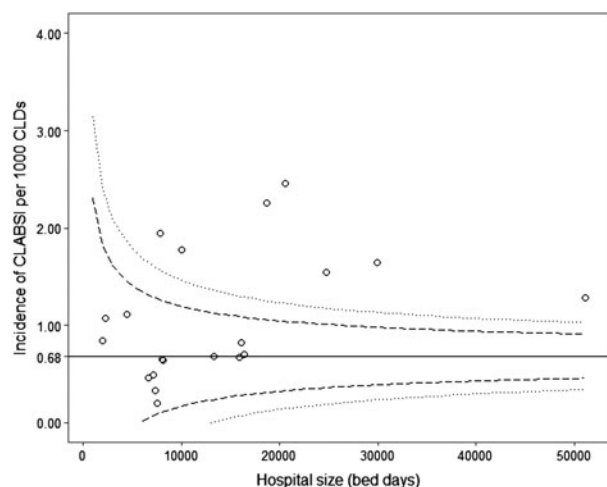


Fig. 1. Funnel plot of CLABSI rates according to hospital size (2010–2013). CLABSI, central line associated bloodstream infection; CLD, central line days.

days in 2011, 1.00 (95% CI 0.75–1.30)/1000 CVC days in 2012 and 0.93 (95% CI 0.69–1.24)/1000 CVC days in 2013. Mean incidence was 0.83 CLABSI per 1000 CVC days (s.d. 0.73). Six sites recorded zero CLABSI cases across the observation period. The distribution of site-level CLABSI incidence as a function of hospital size (bed days) is provided as a funnel plot in [Figure 1](#). The median age of ICU-admitted patients was 66 years (IQR 64.4–68.5). Characteristics of ICU-admitted patients during the study period are summarised in [Table 2](#).

The median number of beds in studied ICUs was 12 (IQR 8–15), with median bed occupancy of 77%. Allocated resources for participating ICUs included median nursing and medical full-time equivalents of 49.8 (IQR 32.5–81.7) and 1.2 (0–4.5) per ICU per year, respectively. [Table 3](#) summarises key site characteristics of participating ICUs.

In the combined model containing all available potential patient- and hospital-level risk factors for infection, independent risk factors included annual number of patients with known mortality (RR 1.11; 95% CI 1.04–1.19; $P = 0.002$), median APACHE III scores (RR 1.03; 95% CI 1.01–1.06; $P = 0.031$), total hours invasively ventilated (RR 1.14; 95% CI 1.08–1.21; $P < 0.001$), and total hours non-invasively ventilated (RR 1.01; 95% CI 1.01–1.02; $P < 0.001$). Factors independently associated with reduced infection risk included ventilation in first 24 h (RR 0.85, 95% CI 0.77–0.94; $P = 0.002$) and an existing policy of mandatory ultrasound guidance for CVC localisation (RR 0.47; 95% CI 0.35–0.64; $P < 0.001$). Of the 26 sites included in the analysis, 12 (46%) reported mandatory US guidance

policy during the observation period. [Table 4](#) summarises univariate and multivariate analyses of covariates included in the adjusted model.

When non-modifiable risk factors only were modelled, the number of non-invasively ventilated patients per total bed days was identified as an independent risk factor for infection (RR 1.07; 95% CI 1.01–1.13; $P = 0.030$). Older age was independently associated with protection against infection (RR 0.94; 95% CI 0.90–0.99; $P = 0.020$). [Table 5](#) summarises modelling of non-modifiable risk factors for CLABSI.

When modifiable risk factors only were modelled, any form of ventilation was associated with increased risk of infection. Total invasively ventilated hours (RR 1.12; 95% CI 1.06–1.18; $P < 0.001$) and total non-invasively ventilated hours (RR 1.01; 95% CI 1.01–1.02; $P < 0.001$) were retained as independent risk factors for infection, both standardised to total ICU bed days. The existence of a policy for mandatory ultrasound guidance for CVC localisation (RR 0.51; 95% CI 0.37–0.70; $P < 0.001$) and number of sessional specialist FTE (RR 0.52; 95% CI 0.29–0.93; $P = 0.027$) were independently associated with protection against infection. [Table 6](#) summarises modelling of modifiable risk factors for CLABSI. When hospital ICUs identified as outliers with respect to CLABSI rates ($n = 7$, [Fig. 1](#)) were compared with non-outlier facilities, there was a non-significant trend toward outlier facilities having a smaller time period in which ultrasound policy was available (29% vs. 33% of interval years, $P = 0.712$) and lower specialist FTE (mean 0.96 vs. 1.07 specialist FTE per 1000 bed days, $P = 0.521$).

DISCUSSION

Our study demonstrates a relationship between development of CLABSI in ICU patients and both staff resources and CVC insertion practices. Although the disease burden and epidemiology of CLABSI in Australian ICUs has previously been reported [[13](#), [19](#)], the relationship between CLABSI and ICU processes and resource allocation has not been evaluated. This is therefore the first Australian study to explore organisation-wide factors, which are associated with CLABSI risk. Given the increasing use of CLABSI as a performance indicator in healthcare facilities [[20](#)], it is essential and necessary for such factors to be evaluated, in order that modifiable factors are contained within future prevention programs.

CDC consensus guidelines for the prevention of intravascular catheter-related infections include the

Table 2. Patient characteristics: aggregate annual data for ICU-admitted patients, 2010–2013

Patient characteristics	Median (IQR)
Age (years)	66 (64–68·5)
APACHE III score	49 (46–55)
Predicted risk of death from APACHE III scoring system	5·14 (3·28–7·08)
Patients with sepsis admission diagnosis code ^a	45 (29–76)
Patients with any infection admission diagnosis code ^b	101 (65–149)
Patients with any infection who meet SIRS and organ dysfunction criteria in first 24 h of ICU	29 (14–47)
Burns	0 (0–1)
Metastases, lymphoma, leukaemia	35 (17–67)
Immunosuppressed by disease, therapy or AIDS	40 (7–75)
Number with invasive mechanical ventilation in first 24 h of ICU	210 (75–729)
Number of first admissions to ICU (i.e. number of patients)	765 (599–1223)
Number of patients with a survival outcome listed	741 (588–1193)
Number of patients who were readmitted to ICU	34 (15–68)
Number of patients who died in hospital	78 (44–142)
Total number of ICU admissions submitted to the ANZICS APD	795 (634–1318)
In-hospital mortality (deaths/admissions)	0·11 (0·07–0·13)

APACHE, acute physiology and chronic health evaluation; IQR, inter-quartile range; ICU, intensive care unit; AIDS, acquired immunodeficiency syndrome; SIRS, systemic inflammatory response syndrome; ANZICS, Australia and New Zealand Intensive Care Society; APD, adult patient database.

^a Sepsis admission diagnosis codes included those for sepsis or septic shock (as defined by the ANZICS modification of the APACHE scoring system).

^b Infection admission diagnosis codes included those for sepsis as well as pneumonia, central nervous system infection, cellulitis and localised soft tissue infections, cholecystitis/choolangitis or gastrointestinal perforation/peritonitis (as defined by the ANZICS modification of the APACHE scoring system).

Table 3. ICU annual characteristics: 2010–2013 (*n* = 26 sites)

Site characteristics	
Modifiable factors (annual)	
● Number of infective diagnosis – median (IQR)	98 (67, 151)
● Patients ventilated in first 24 h – median (IQR)	142 (64, 697)
● Policy of mandatory ultrasound guidance for CVC localisation – <i>n</i> (%)	12 (46·2)
● Number of registered nurse FTE – median (IQR)	48 (25, 81)
● Total invasively ventilated hours – median (IQR)	13 357 (4479, 39752)
● Total non-invasively ventilated hours – median (IQR)	931 (172, 5391)
● Number of salaried specialists FTE – mean (s.d.)	2·6 (3·3)
● Number of sessional specialists FTE – mean (s.d.)	1·1 (1·6)
● Total number of non-intensive care specialists FTE – mean (s.d.)	0·3 (0·7)
Non-modifiable factors (annual)	
● Number of patients with known mortality – median (IQR)	700 (578, 1226)
● Age (years) – mean (s.d.)	62·6 (4·7)
● APACHE III score – mean (s.d.)	54·4 (7·8)
● Number of invasive ventilation – median (IQR)	48 (5, 294)
● Number of non-invasively ventilated patients – median (IQR)	28 (0, 204)

CVC, central venous catheter, APACHE, acute physiology and chronic health evaluation; IQR, inter-quartile range; ICU, intensive care unit; FTE, full time equivalent; s.d., standard deviation.

recommendation that ultrasound guidance be used to place CVCs, if this technology is available [21]. The rationale for this recommendation is that ultrasonography has been shown to reduce the number of

cannulation attempts and mechanical complications [22]. Although one observational study has demonstrated no reduction in CLABSI risk with ultrasound-guided CVC insertion [23], two pooled studies spanning

Table 4. *Unadjusted and adjusted analysis of potential risk factors for CLABSI*

Characteristic	Unadjusted RR (95% CI)	P-value	Adjusted RR (95% CI)	P-value
Any infective diagnosis ^a	1.34 (1.15–1.56)	<0.001	1.14 (0.88–1.46)	0.316
Ventilated in first 24 h ^a	1.06 (1.03–1.09)	<0.001	0.85 (0.77–0.94)	0.002
Annual number of patients with known mortality ^a	1.05 (1.03–1.07)	<0.001	1.11 (1.04–1.19)	0.002
Median APACHE III score	1.05 (1.03–1.07)	<0.001	1.03 (1.01–1.06)	0.031
Policy of mandatory ultrasound guidance for localisation for CVC cannulation	0.60 (0.43–0.78)	<0.001	0.47 (0.34–0.64)	<0.001
Total invasively ventilated hours per TBD	1.06 (1.02–1.10)	0.001	1.14 (1.08–1.21)	<0.001
Total non-invasively ventilated hours per TBD	1.00 (1.00–1.01)	0.001	1.01 (1.01–1.02)	<0.001

CLABSI, central line-associated bloodstream infections; ICU, intensive care unit; RR, relative risk; 95% CI, 95% confidence interval; FTE, full-time equivalent; APACHE, acute physiology and chronic health evaluation; TBD, total ICU bed days; CVC, central venous catheter.

^a Units of 100.

Table 5. *Non-modifiable risk factors for CLABSI: unadjusted and adjusted analysis*

Characteristic	Unadjusted RR (95% CI)	P-value	Adjusted RR (95% CI)	P-value
Annual number of patients with known mortality	1.05 (1.03–1.07)	<0.001	1.01 (0.98–1.05)	0.534
Median age	0.92 (0.89–0.95)	<0.001	0.94 (0.90–0.99)	0.020
Median APACHE III score	1.05 (1.03–1.07)	<0.001	^a	
Number of invasive ventilations per 100 TBD	1.02 (1.01–1.04)	0.029	1.01 (0.98–1.03)	0.529
Number of non-invasively ventilated patients per 100 TBD	1.06 (1.01–1.12)	0.012	1.07 (1.01–1.13)	0.030

CLABSI, central line-associated bloodstream infections; RR, relative risk; 95% CI, 95% confidence interval; APACHE, acute physiology and chronic health evaluation; TBD, total ICU bed days.

^a Given the inclusion of age in APACHE III, this variable is not included independently in multivariate model.

a range of patient populations and medical devices have demonstrated benefit for prevention of CLABSI [24, 25]. Our findings concur with these pooled studies, and support the routine use of ultrasound guidance for CVC localisation as a means of reducing risk of CLABSI by approximately 50%. Recognising that the ICU medical workforce may not be fully trained in ultrasound technique, we support current international consensus guidelines but also suggest evaluation of workforce skills be performed to determine the feasibility of routine ultrasound guidance in all Victorian centres.

Furthermore, we identified staff resources, particularly the availability of sessional medical specialists as contributing significantly to reduced CLABSI risk. This is consistent with the fact that practice in Australian ICUs is for medical staff (rather than nursing staff) to insert CVCs, and that increased medical staffing may therefore increase the available time for optimal CVC insertion practices. Others have reported limited clinical staffing as a risk for

CLABSI in neonatal ICUs [26] and nursing staff reductions as a contributing factor to increased CLABSI risk [27, 28]. In contrast, we did not identify nursing staff resources as a significant contributor to CLABSI risk. These findings may be uniquely relevant to the workforce employed in Australian ICUs. Increased sessional, but not salaried medical specialist resources, were associated with reduced risk for CLABSI. In Australia, the appointment of sessional specialists may occur in the setting of service expansion and increased funding for an ICU, and sessional staff may be visiting medical officers with appointment across multiple ICUs within a number of health-care facilities. In addition, these staff tend to be specialists who have more recently completed final exit specialisation exams in Intensive Care practice. It is possible that some of these factors could impact upon CLABSI risk within an ICU – for example, a mobile workforce may be more obliged to be familiar with local infection prevention policies, may be more likely to be up-to-date with recent infection control

Table 6. Modifiable risk factors for CLABSI: unadjusted and adjusted analysis

Characteristic	Unadjusted RR (95% CI)	P-value	Adjusted RR (95% CI)	P-value
Any infective diagnosis ^a	1.13 (1.15–1.56)	<0.001	1.28 (0.99–1.65)	0.061
Ventilated in first 24 h ^a	1.06 (1.03–1.09)	<0.001	0.97 (0.92–1.03)	0.308
Policy of mandatory ultrasound guidance for localisation for central venous cannulation	0.60 (0.43–0.78)	<0.001	0.51 (0.37–0.70)	<0.001
Number of registered nurse FTE per 100 TBD	0.94 (0.82–1.08)	0.393	0.86 (0.67–1.11)	0.251
Total invasively ventilated hours per TBD	1.06 (1.02–1.10)	0.001	1.12 (1.06–1.18)	<0.001
Total non-invasively ventilated hours per TBD	1.00 (1.00–1.01)	0.001	1.01 (1.01–1.02)	<0.001
Number of salaried specialists FTE per 1000 TBD	1.01 (0.79–1.30)	0.963	0.81 (0.52–1.24)	0.330
Number of sessional specialists FTE per 1000 TBD	0.66 (0.48–0.91)	0.012	0.52 (0.29–0.93)	0.027
Total number of non-intensive care specialists FTE per 1000 TBD	0.67 (0.50–0.90)	0.007	0.36 (0.06–2.27)	0.278

CLABSI, central line-associated bloodstream infections; RR, relative risk; 95% CI, 95% confidence interval; FTE, full-time equivalent; TBD, total ICU bed days.

^a Units of 100.

literature and more likely to use ultrasound routinely for CVC insertion.

We also demonstrated that any form of ventilation was associated with increased risk of CLABSI. While the reasons for this are not clear, others have also observed an association between infection and mechanical ventilation [29, 30], and it is possible that respiratory infection in the setting of ventilation could predispose to bloodstream infection, or that patients in the ICU environment may become colonised at multiple sites (e.g. respiratory tract and CVC) with pathogens such as MRSA and *Candida* spp., both of which are recognised causes of CLABSI [31].

When hospital ICUs identified as outliers in the current study with respect to CLABSI rates (Fig. 1) were compared with non-outlier facilities, we observed a trend toward smaller time period in which ultrasound policy was available and lower specialist FTE. Although not statistically significant, this observation is consistent with risk factor analysis performed in our study and the fact that these modifiable factors hold clinical significance.

The context for this study must be understood prior to applying findings to populations in other regions. A national hand-hygiene program has been operational in Australia for 7 years, and compliance with WHO moments for hand hygiene is a focus for high risk wards, including ICU staff [32]. Also, all ICUs included in our study had competency standards for CVC insertion, ward rounds with an infectious diseases specialist or microbiologist, rounds with a pharmacist, an antimicrobial stewardship program,

infection prevention policy, generation of regular anti-biograms specific to the ICU and a critical incident monitoring program. Regionally, quality improvement has been a focus in all Victorian hospitals, with infections in ICUs comprising one element of statewide performance monitoring [33]. This is reflected by the observation that overall CLABSI rates diminished during the studied 4 year period (from 1.72 to 0.93/1000 CVC days).

We identified older age as being protective for CLABSI, and this contrasts with other studies reporting increased risk for CLABSI in elderly patients [34]. While the reasons for this are not clear, it is possible that the studied population represented a cohort of elderly patients with higher functional capacity and reduced infection risk, as these patients had been admitted to ICU and were considered eligible for active care. Conversely, those patients with poorer prognosis (and potentially higher risk for CLABSI) would be more likely to be managed conservatively in a ward environment, and therefore not have been included in the current study. In a large retrospective study of ICU-admitted patients spanning 15 years, Blot *et al.* reported decreased incidence of bloodstream infections in elderly ICU patients, with the proportion of all bloodstream infections in very elderly patients attributed to a venous catheter being only 13% [35]. Results of the current study support these findings.

One limitation of our study is the fact that an existing dataset of ICU resources was used, and this has not been specifically formulated for the purposes of infection risk surveillance. Nonetheless, we believe

many plausible risk factors for CLABSI to have been adequately captured by the dataset (e.g. age, patient co-morbidities, presence of other infections). In the absence of an accepted tool or previously published framework for classifying risk factors, the definition of modifiable and non-modifiable risk factors used in our study was based on clinical consensus. For example, the duration of ventilation for intubated patients is generally minimised by clinicians, and this was therefore regarded as a modifiable factor. The availability of non-invasive ventilatory support in a step-down or ward setting could impact the number of invasively-ventilated patients in a given ICU, and this capacity requires dedicated resources outside of ICU. Management of concurrent infections can be optimised by early identification and targeted therapy. Prevention of concurrent healthcare-associated infections (e.g. healthcare-associated pneumonia or bloodstream infection) requires effective and appropriately resourced hospital-wide infection prevention programs (e.g. implementation of evidence-based bundles of care), therefore other infective diagnoses were similarly considered as modifiable. We believe our classification to be a viable and pragmatic basis for evaluating organisational factors amenable to human resourcing or financial support. Other limitations include the fact that studied healthcare facilities may not be representative of all Australian hospitals, potentially limiting the generalizability of findings. In addition, information from ANZICS CORE annual surveys was used, but some of this hospital-level information may have changed over time.

Study strengths include the representativeness of participating ICUs in our region, with 26/37 sites being eligible for inclusion (70.3%), all of which were evaluated in the current study. Also, we believe that partitioning of modifiable and non-modifiable risks is a pragmatic and necessary step to adequately inform prevention strategies at the hospital-level. Quality improvement programs can then focus upon those factors that are potentially reversible, in order to optimise outcomes and rationalise resources.

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