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Research paper

Unnecessary removal of vascular access devices due to suspected infection in Australian intensive care units

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ABSTRACT

Background: Vascular access devices suspected of infection are often removed unnecessarily and frequently require replacement. The aim of this study was to identify the prevalence and economic impact of premature, unnecessary device removal due to suspected infection in adult patients admitted to the intensive care unit.

Methods: Secondary data analysis of a prospectively collected data set detailing central venous catheters and peripheral arterial catheters in 1458 adult patients was conducted in nine Australian intensive care units. Data extracted from the parent database included patient demographics, device, and infection-specific data including the reason for device removal. Cost estimates were based on a recently published review of device utilisation and associated costs in Queensland public hospitals.

Results: A total of 6144 central venous catheter days and 4696 arterial catheter days were studied. Median device dwell time was 7.2 (interquartile range: 5.6–9.0) days for central venous catheters and 6.5 (interquartile range: 4.8–8.5) days for arterial catheters. Device removal due to suspected infection occurred at a rate of 25.7 and 15.3 episodes/1000 catheter days in central venous and arterial catheters, respectively. Central venous and arterial catheter–related bloodstream infections occurred at a rate of 1.8 and 0.2 episodes/1000 catheter days, respectively. Central line–associated bloodstream infection occurred at a rate of 3.3 episodes/1000 catheter days. Local central venous and arterial catheter infection occurred at 0.16 and 0.02 episodes/1000 catheter days, respectively. The difference in incidence between devices suspected of infection and those responsible for infection resulted in AUD$67,087 unnecessarily spent on device replacement.

Conclusions: Unnecessary device removal due to suspected infection presents a substantial clinical problem which is costly for the healthcare organisation and time-consuming for clinicians and places the patient at an increased risk of iatrogenic complications. There is a need for robust evidence and clinical practice guidelines to inform clinical decision-making to reduce unnecessary device removal.

1. Introduction

Vascular access devices (VADs), particularly peripheral arterial catheters (ACs) and nontunneled central venous catheters (CVCs), play a vital, multifaceted role in modern-day intensive care clinical practice. Arterial catheters facilitate rapid blood sampling and continuous, real-time haemodynamic monitoring[1] and as a result are the most frequently manipulated catheters used in the intensive care unit (ICU).[2] CVCs enable central venous pressure monitoring;[3] administration of irritant intravenous medications, fluids, and blood products; parental nutrition; and blood sampling.[4] Multiple lumen CVCs allow concurrent administration of different types of medications whilst reducing numerous, repeated needle insertions,[3] which is particularly relevant in the critically ill ICU patient population who often require multiple inotropic agents, intravenous sedation, and nutrition to facilitate their treatment.

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Despite their clinical importance, VADs are also associated with complications such as local infection and systemic bloodstream infection (BSI).[1,5] VAD-related BSIs are costly complications which increase mortality.[6,7] Infective complications of VAD use are viewed as a preventable source of patient harm and have significant impact on healthcare budgets.[5] Each diagnosis of CVC-related infection costs an added AUD$34,843[8] (USD$32,000[5,9]) and extends ICU admission by more than 4 days[5,10] and hospital length of stay by 16.8 days.[8]

Clinicians may suspect VAD-related infection when the patient exhibits unexplained signs of sepsis, namely fever and increasing white blood cell (WBC) count. VADs suspected of infection are the commonly removed ones as a primary method of source control to hasten microbiological clearance, thereby reducing the risk of end-organ damage and further damage due to continuing inflammatory processes.[11] However, removal is often performed despite a lack of laboratory-confirmed bacteraemia.[12] The proportion of VADs removed on suspicion of infection which, after results of catheter tip and blood cultures become available, prove not to be infected can be as high as 91%.[12,13] It has been postulated that this rate of unnecessary removal is highest in the ICU patient cohort as this patient group frequently exhibits unexplained fevers,[12] not all of which stem from infectious sources.[14]

Patients frequently require the insertion of a new VAD to continue their treatment after their initial VAD is removed for suspected infection.[15] Unnecessary and premature removal of VADs exposes patients to an increased risk of complications associated with VAD reinsertion, such as increased discomfort,[16] pain and distress,[17] vascular lesions, haematoma, haemothorax, pneumothorax, nerve injury, and gas embolism.[18] Reinsertion of VADs is also time-consuming for clinical staff,[12] particularly in those patients with difficult vascular access, resulting in patients experiencing treatment delays if the catheter cannot be promptly replaced.[5] Finally, replacement of VADs is costly to the healthcare organisation, with a study calculating the insertion and removal (including equipment, labour, and accessories expenditure) of a CVC costs approximately AUD$375 and an AC AUD$161.[19]

The aim of this secondary data analysis was to describe the prevalence and economic impact of unnecessary CVC and AC removal due to suspected infection in the adult intensive care cohort.

2. Methods

2.1. Parent study

This study used data from a large multicentre randomised controlled trial that compared 4- and 7-day VAD administration set replacement.[20,21] Data were collected in 10 major hospitals across Australia from May 2011 to December 2015 and included a total of 2941 adult and paediatric patients admitted to acute medical, surgical oncology, haematology, and critical care wards. Ethics committee approval was obtained in Queensland, New South Wales, Western Australia, and from Griffith University. Inclusion criteria comprised of patients requiring a central venous (including peripherally inserted catheters [PICCs]) and/or peripheral arterial VAD *in situ* for greater than 24 h with an anticipated dwell time of at least 7 days. Exclusion criteria were as follows: (i) documented BSI within the 24 h before study enrolment; (ii) anticipated removal of the catheter within 24 h; (iii) catheter *in situ* for more than 96 h at the time of screening; and (iv) original administration set already replaced.

2.2. Secondary data analysis

This secondary data analysis included all adult patients with suspected or confirmed CVC- or AC-related infection. Ethics approval was obtained from Griffith University HREC (reference number 2019/274) before commencement of data extraction. Data specific to the secondary analysis research questions were extracted from the parent database and included age, sex, weight, reason for ICU admission, days in hospital and ICU before study entry, Acute Physiology, Age, Chronic Health Evaluation (APACHE) II score, history of diabetes, and WBC count $< 10^9$ g/L. VAD-specific data included whether or not it was a difficult insertion, patient location at the time of insertion, anatomical insertion site, and reason for VAD removal. Infection-specific data included catheter tips sent for analysis on VAD removal, organisms responsible for infection, and insertion site characteristics/appearance at the time of removal. VADs that met the central line–associated bloodstream infection (CLABSI),[22] catheter-related bloodstream infection (CRBSI),[23] and localised infection[24] criteria were classified as part of the primary analysis of the parent database by an infectious diseases specialist and included in this secondary analysis.

2.3. Definitions

Localised VAD insertion site infection and VAD-associated BSI were considered as two separate outcomes. The definition of catheter-related BSI was applied to both CVCs and ACs and was defined as one of[1] positive blood culture and tip with matching organism $\geq$15 CFU (Category 1),[2] two blood cultures (VAD and peripheral) with three-fold greater colony count from VAD, or differential time to positivity (DTP) from VAD culture at least 2 h before peripheral (Category 2), or[3] two blood cultures from two catheter lumens with three-fold greater count in one lumen compared to the second lumen (Category 3).[23]

The definition of CLABSI was only applied to CVCs and was defined as a CVC that had been in place for more than 2 consecutive calendar days (on or after the 3rd CVC dwell day), after the first access of the central line in an inpatient location during the patient's current admission and either[1] patient has a recognised pathogen from $\geq$1 blood culture, and the organism is not related to an infection at any other site (Category 1), or[2] patient has fever (>38 °C), chills, or hypotension, and organism is not related to an infection at another site, and a common skin commensal is cultured from $\geq$2 blood cultures drawn on separate occasions within a 24 h timeframe (Category 2).[22]

CVC localised infection was defined as purulent phlebitis confirmed with a positive semiquantitative culture of a catheter tip, but with either a negative or no blood culture (Category 1).[24] Arterial catheter localised infection was defined as[1] purulent drainage from vascular site (Category 1) or[2] patient has at least one of the following signs or symptoms: fever (>38 °C), pain, erythema or heat at involved vascular site with no other recognised cause, and $\geq$15 CFU from the intravascular cannula tip (Category 2).[24]

2.4. Statistical analysis

One patient record was removed as part of data cleaning as it did not state whether the device was a CVC or AC. Other missing data were not imputed. Incidence (episodes per 1000 catheter days) of VAD removal due to suspected infection, CRBSI, CLABSI, and local infection was calculated by dividing the number of episodes by the total number of VAD dwell days. Results for CVCs and ACs were

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calculated separately. Statistical analysis was performed using IBM SPSS (version 25, Armonk, New York, USA). Frequencies and proportions were reported for categorical data. Means and standard deviations (SDs) were reported for normally distributed continuous data, while medians and 25th and 75th percentiles were reported for continuous data which were not normally distributed.

2.5. Cost analysis

Given the study cohort were critically ill patients, it was assumed that all VADs which 'failed' (i.e., those that were removed for any indication other than 'treatment complete', 'routine replacement', or 'deceased') were replaced to facilitate the patient's continued treatment. The cost of premature removal was calculated using the same method as reported previously.[19] Resources consumed included equipment, accessories, and staff time required to insert and remove catheters. Equipment costs were valued at negotiated hospital prices, and staff time was valued at the fixed industrial award wages in Australia. Initial device removal, maintenance costs, and costs of treating complications were excluded.

3. Results

3.1. Patient population

A total of 1458 adult ICU patients were included in this study, comprising 793 patients with CVCs and 665 patients with ACs. Demographic data were similar between CVC and IAC patient groups and are reported in Table 1. The mean patient age at the time of study enrolment was 57 years, with the majority (66%) of patients being male, a median weight of 82 kg (interquartile range [IQR]: 70–96), and a median APACHE II score of 20 (SD: 7). Forty-seven percent of patients were admitted with a medical diagnosis, while one quarter were surgical patients.

Median VAD dwell time was 7.2 (IQR: 5.6–9.0) days for CVCs and 6.5 (IQR: 4.8–8.5) days for ACs. The majority of VADs (63%) were inserted in the ICU or operating theatre (26%). Most CVCs were placed in the internal jugular vein (73%), while the majority of ACs were inserted into the radial artery (83%). Only 7% (n = 53) of VAD insertions were classified as 'difficult' insertions.

3.2. Catheter tip colonisation

One hundred fifty-eight (69%) CVCs and 72 (31%) ACs were removed for suspicion of infection. Of these CVCs and ACs, only 16% (n = 36) had a catheter tip sent for analysis at VAD removal (CVCs n = 41; ACs n = 5); see Table 2). Twenty-eight percent (n = 10) of catheter tips were positive for microorganism growth ≥15 CFU, 14% (n = 5) were positive for growth <15 CFU, while 58% (n = 21) returned negative for microorganism growth.

In comparison, VADs removed for indications other than suspected VAD-related infection totaled 1,228, with only 3% (n = 37) of these VADs having the tip sent for analysis. The majority (71%, n = 22) of these tips were negative for microorganism growth, 16% (n = 5) positive for growth ≥15 CFU, and 13% (n = 4) positive for growth <15 CFU.

Organisms responsible for colonisation in CVCs were varied. However, the most common was coagulase-negative

Table 1
Patient demographics.

Variable	CVC	AC	Total
Group size, n	793	665	1458
Age (years), mean (SD)	57 (16)	57 (17)	57 (17)
Sex: male	513 (65)	449 (68)	962 (66)
Weight (kg), median (IQR)	82 (70–96)	83 (70–96)	82 (70–96)
Reason for ICU admission			
Medical	371 (47)	317 (48)	688 (47)
Emergency surgical (not trauma)	124 (16)	106 (16)	230 (16)
Cardiac surgical	126 (16)	86 (13)	212 (15)
Trauma (not burns)	114 (14)	60 (9)	174 (12)
Elective surgical (not cardiac)	49 (6)	84 (13)	133 (9)
Other	9 (1)	12 (2)	21 (1)
Days in hospital at study enrolment, median (IQR)	4 (3–6)	4 (3–7)	4 (3–7)
Days in ICU at study enrolment, median (IQR)	3 (2–4)	4 (3–4)	4 (3–4)
APACHE II score	20 (15–24)*	19 (7)^	20 (7)^
Diabetes	164 (21)	127 (19)	291 (20)
WBC < 10^9/L	15 (2)	21 (2)	36 (3)
Difficult insertion	38 (5)	15 (2)	53 (7)
Location at time of insertion			
ICU	488 (62)	424 (64)	912 (63)
OT	210 (27)	174 (26)	384 (26)
Emergency	52 (7)	40 (6)	92 (6)
Another hospital	28 (4)	24 (4)	52 (4)
Other	14 (2)	3 (1)	18 (1)
Anatomical insertion location (CVC)			
Internal jugular	573 (73)	–	573 (39)
Subclavian	109 (14)	–	109 (8)
Femoral	104 (13)	–	104 (7)
Other	7 (1)	–	7 (1)
Anatomical insertion location (AC)			
Radial	–	551 (83)	551 (38)
Femoral	–	51 (8)	51 (4)
Dorsalis pedis	–	15 (2)	15 (1)
Other	–	48 (7)	48 (3)

All variables are reported as n (%) unless otherwise specified.
APACHE = Acute Physiology, Age, Chronic Health Evaluation; WBC = white blood cell; ICU = intensive care unit; OT = operating theatre; CVC = central venous catheter; AC = arterial catheter; * = median (interquartile range); ^ = mean (standard deviation).

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Table 2
Catheter tip colonisation.

Variable	VADs removed for suspected VAD-related BSI	VADs removed for other indications	All CVCs	CVCs removed for suspected VAD-related BSI	All ACs	ACs removed for suspected VAD-related BSI
Group size, n	230	1228	793	158	665	72
Catheter tips sent	36 (16)	31 (3)	46 (6)	41 (26)	21 (3)	5 (7)
Tip growth						
-ve growth	21 (58)	22 (71)	28 (61)	17 (42)	15 (71)	4 (80)
+ve growth <15 CFU	5 (14)	4 (13)	6 (13)	4 (10)	3 (14)	1 (20)
+ve growth ≥15 CFU	10 (28)	5 (16)	12 (26)	10 (24)	3 (14)	0
Organisms (≥15 CFU only)						
Acinetobacter baumannii complex			1 (8)		–	
Enterobacter cloacae			1 (8)		–	
Enterococcus faecalis			1 (8)		–	
Klebsiella oxytoca			1 (8)		–	
Klebsiella pneumoniae & coagulase negative *staphylococcus*			2 (17)		–	
Coagulase negative *staphylococcus*			4 (33)		–	
Serratia marscecens			1 (8)		–	
Mixed skin flora			1 (8)		–	
Candida spp.			–		2 (67)	
Proteus mirabilis			–		1 (33)	

All variables are reported as n (%) unless otherwise specified.
VAD = vascular access device; CFU = culture-forming units; BSI = bloodstream infection; CVC = central venous catheter; AC = arterial catheter.

Staphylococcus (33%) or dual colonisation of *Klebsiella pneumoniae* and coagulase-negative *Staphylococcus* (17%). *Candida* spp. was most commonly responsible for AC colonisation (67%), followed by *Proteus mirabilis* (33%) (see Table 2).

3.3. VAD-related BSIs

In this study, 6,144 CVC days and 4696 AC days were studied. VAD removal due to suspected infection occurred at a rate of 25.7 and 15.3 episodes per 1000 catheter days in CVCs and ACs, respectively.

Eleven (1%) CVCs and one (0.2%) AC met CRBSI Category 1 criteria,[23] equaling an infection rate of 1.8 and 0.2 episodes per 1000 catheter days, respectively (see Table 3). No VAD met CRBSI Category 2 or 3 criteria. When defined against the CLABSI criteria,[22] 2% of CVCs met Category 1 criteria, while 0.5% of CVCs met Category 2 criteria, totaling an infection rate of 3.3 episodes per 1000 catheter days. Seven CVCs (all of which were removed for suspected infection) met both CRBSI and CLABSI criteria.

Devices suspected of VAD-related BSI totaled 1243 CVC days and 511 AC days. Rate of CRBSI in this subgroup was 8.0 and 0 episodes per 1000 catheter days for CVCs and ACs, respectively, while CLABSI rates were 10.5 episodes per 1000 CVC days. No ACs in this group were responsible for BSI.

3.4. Local infections

One AC (0.2%) and one CVC (0.1%), both of which were removed for a reason other than suspected infection, met localised infection criteria,[24] totaling an infection incidence of 0.02 and 0.16 episodes per 1000 catheter days, respectively (see Table 3). VADs removed on suspicion of infection were documented to have a less 'normal' appearance (77% versus 93%) and more redness evident at the insertion site (20% versus 4%) than those VADs removed for other indications (see Table 4).

3.5. Cost analysis

Premature removal of VADs due to device failure in this analysis cost healthcare organisations across Australia an estimated AUD$95,859 associated with VAD replacement (see Table 5). VADs removed on suspicion of infection but not positive for infection totaled 220 devices, costing an estimated AUD$67,087 unnecessarily spent on replacement costs.

4. Discussion

This study has highlighted the clinical issue of premature VAD removal due to suspected infection within the adult intensive care setting. CVCs and ACs were removed on suspicion of infection at rates much higher than the incidence of actual infection (25.7 and 15.3 episodes per 1000 catheter days, respectively, versus 1.8 and 0.2 episodes per 1000 catheter days, respectively [CRBSI] and 0.16 and 0.02 episodes per 1000 catheter days, respectively [local infection]). Of the 230 VADs removed for suspected VAD-related BSI, only 10 CVCs were found likely to be responsible for BSI as per CRBSI criteria. This indicates that most VADs suspected of infection were potentially removed unnecessarily, needlessly exposing patients to risk of complications associated with VAD replacement. Unnecessary removal of VADs due to suspected infection in this study also cost healthcare organisations in excess of $67,000, funds which could have been saved if the VADs remained *in situ*.

There is currently a paucity of evidence with regards to clinical management of VADs suspected of infection to guide clinicians in their daily ICU practice. A recent narrative review identified only two studies that address this specific question.[25] Both studies compared immediate removal versus retention of CVCs suspected of infection in adult ICU cohorts, concluding no significant differences in morbidity[12] or 30-day mortality[18] between those patients who had their CVC immediately removed and those who had their CVC initially retained. There have been no such studies that investigate removal versus retention of ACs suspected of infection. This lack of rigorous evidence and ICU-specific clinical practice guidelines are currently exposing ICU patients to unnecessary VAD removal when infection is suspected. It is therefore imperative that evidence-based literature and guidelines be developed to allow ICU clinicians to effectively manage patients suspected of VAD-related infection to reduce the impact of this common clinical scenario on critically ill patients.

In our study, BSI rates were higher in the group of CVCs removed for suspected infection than overall (8.0 versus 1.8 episodes per 1000 catheter days [CRBSI criteria[23]] and 10.5 versus 3.3 episodes per 1000 catheter days [CLABSI criteria[22]]), suggesting some

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Table 3
VAD-related infections.

Variable	All CVCs	CVCs removed for suspected VAD-related BSI	CVCs not removed for suspected VAD-related BSI	All ACs	ACs removed for suspected VAD-related BSI	ACs not removed for suspected VAD-related BSI
Group size, n	793	158	635	665	72	593
Total dwell time, days	6144	1243	4901	4696	511	4185
Removal for suspected infection/ 1000 catheter days	–	25.7	–	–	15.3	–
CRBSI[23]						
Category 1	11 (1)	10 (6)	1 (0.2)	1 (0.2)	0	1 (0.2)
Category 2	0	0	0	0	0	0
Category 3	0	0	0	0	0	0
CRBSI (episodes/1000 catheter days)	1.8	8.0	0.2	0.2	0	0.2
CLABSI[22]						
Category 1	16 (2)	9 (6)	7 (1)	–	–	–
Category 2	4 (1)	4 (3)	0	–	–	–
CLABSI episodes/1000 catheter days	3.3	10.5	1.4	–	–	–
CVC-related local infection[24]						
Category 1	1(0.1)	0	1(0.2)	–	–	–
CVC-related local infection episodes/ 1000 catheter days	0.16	0	0.2	–	–	–
AC-related local infection[24]						
Category 1	–	–	–	1 (0.2)	0	1(0.2)
Category 2	–	–	–	0	0	0
AC-related local infection episodes/ 1000 catheter days	–	–	–	0.02	0	0.2

All variables are reported as n (%) unless otherwise specified.
CRBSI = catheter-related bloodstream infection; CLABSI = central line-associated bloodstream infection; VAD = vascular access device; CVC = central venous catheter; AC = arterial catheter.

reliability in detecting VAD infections at the bedside. However, our data show that there was one CVC and one AC positive for CRBSI and one CVC and one AC positive for localised infection which were not removed due to suspected infection. This indicates that there were four patients who may have been unnecessarily exposed to a continuing source of infection, persistent bacteremia, and continued inflammatory response.[16] This, in turn, may have led to worse prognoses in these patients than others in the study[18,26] and negatively impacted their mortality.[27,28] Reliable methods of diagnosing VAD infections at the bedside are lacking, and further research is needed to determine effective diagnostic methods to improve patient care.

This study also demonstrated differences in the rate of local infection versus BSI (0.16 versus 3.3 episodes per 1000 catheter days in CVCs and 0.02 versus 0.34 episodes per 1000 catheter days in ACs). Interestingly, other published literature documents rates of local infection higher than that of VAD-related BSI[29,30] and is in opposition to our results. Our study identified rates of BSI higher than local infection in both CVCs and ACs. The exact reason for these differences could not be extracted from the parent database but could be due to the majority of microbial contamination of the catheter occurring from a BSI of other origin, rather than from contamination of the VAD insertion site or catheter hub.[31] Differences may also be explained by the varying definitions of localised infection used in our study compared with other literature. Other literature uses broad definitions for both CVC and AC local infections,[5,29,30,32] whereas our study used VAD-specific definitions direct from the CDC guidelines,[24] which may also account for the lower rates of localised infection demonstrated in our study than that of other literature.[29,30] There was also a low proportion of catheter tips cultured from those devices removed for suspected infection, which, if all had been appropriately cultured when these devices were removed, may have resulted in higher BSI and local infection rates. It is therefore imperative device tips be routinely cultured when infection is suspected in clinical practice and, if the suspicion of infection is not high enough to warrant tip culture, that clinicians question whether device removal is truly necessary in the first instance at all.

There are also varying definitions of VAD-related BSI, particularly pertaining to CVCs. In this study, we described CVC-related infections against both CRBSI and CLABSI definitions. We felt that this was necessary as these two sets of criteria are often used interchangeably in the current literature but are intended for different purposes. The CRBSI criteria are intended for definitive

Table 4
Insertion site characteristics at the time of VAD removal.

Variable	All VADs removed for suspected VAD-related BSI	All VADs removed for other indications	CVCs removed for suspected VAD-related BSI	ACs removed for suspected VAD-related BSI
Group size, n	230	1228	158	72
Insertion site characteristics on VAD removal				
Normal	176 (77)	1147 (93)	115 (73)	61 (85)
Painful	2 (1)	10 (1)	2 (1)	0
Red	46 (20)	45 (4)	35 (22)	11 (15)
Swelling present	1 (1)	9 (1)	1 (1)	0
Nonpurulent discharge	7 (3)	19 (2)	7 (4)	0
Purulent discharge	1 (1)	3 (1)	1 (1)	0

All variables are reported as n (%) unless otherwise specified.
VAD = vascular access device; CVC = central venous catheter; AC = arterial catheter; BSI = bloodstream infection.

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Table 5
Cost of premature VAD removal.

Variable	CVCs removed due to device failure	ACs removed due to device failure	CVCs removed for suspected infection never confirmed	ACs removed for suspected infection never confirmed
Group size, n	186	162	148	72
Equipment cost	13,870	3532	11,013	1570
Labour cost	54,760	22,453	43,573	9979
Accessories cost	1140	104	907	46
Total cost	69,770	26,088	55,493	11,595

All costs are in AUD.
CVC = central venous catheter; AC = arterial catheter; VAD = vascular access device.

diagnoses, whereas the CLABSI criteria are used for general surveillance of CVC-related infections and as such often overestimate the true incidence of CRBSI.[33] The difference in these definitions was evident in our results, with CLABSI criteria producing an incidence rate almost twice that of CRBSI criteria. This difference has highlighted the need for improved definitions and reporting criteria, which may reduce confusion amongst clinicians as to what criteria to use when assessing their patients for CVC-related BSI and allow patients who fit criteria to be promptly and effectively treated, thereby reducing associated morbidity and mortality.

To our knowledge, this is the first study to quantify the financial implications of premature and potentially unnecessary removal of VADs generally, with a specific focus on those suspected of infection. It is also the first study that has estimated the savings that could be made if management practice of VADs in the ICU, particularly those suspected of infection, is improved. It is important this waste is quantified, as it may incentivise organisations to be more proactive in optimising postinsertion care to prevent device failure.[19] In this analysis, premature removal of CVCs suspected of infection which were not actually infected cost healthcare organisations across Australia a total of $55,492.60, while premature removal of ACs suspected of infection cost $11,594.88. When extrapolated out Australia-wide, this equates to $7,861,797 unnecessarily spent (public hospitals only). However, we were unable to quantify the cost of initial VAD removal, replacement VAD maintenance, or costs of complications. As such, the estimated costs presented in this study could be slightly higher if these additional costs, and device usage in private hospitals, were taken into consideration. This represents a significant burden on an already overstretched healthcare budget, and these additional costs could be reduced or completely abolished if more reliable methods of managing VADs suspected of infection could be developed.

Our study does have limitations. First, the secondary data analysis framework did not allow us to investigate all variables to answer the research question. For example, we were unable to assess what portion of those VADs removed on suspicion of infection required immediate replacement to continue the patient's treatment. Second, not all VADs removed for suspected infection had tips sent for culture. This significantly reduced our ability to apportion infection outcomes, particularly with respect to CRBSI and local infection criteria. This may have resulted in the rates of reported infection being lower than actual infection rates. Finally, Tuffaha et al. calculated only cost of VADs in Queensland public hospitals;[19] generalisability across other Australian states and globally is somewhat limited. Therefore, the cost analysis should be considered an estimation of the potential amount of financial waste associated with removal of VADs due to suspected infection if all VADs prematurely and unnecessarily removed necessitated immediate replacement.

5. Conclusions

Unnecessary VAD removal due to suspected infection presents a substantial clinical problem which is costly for the healthcare organisation and time-consuming for clinicians and places the patient at an increased risk of iatrogenic complications. There is an urgent need to explore rapid methods of detection of suspected VAD infection and for the development of robust clinical practice guidelines to inform clinical decision-making to reduce the impact of unnecessary VAD removal.

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CRediT authorship contribution statement

India Pearse: Methodology, Project administration, Investigation, Data curation, Visualisation, Writing – original draft, Writing – review and editing. **Amanda Corley**: Conceptualisation, Methodology, Supervision, Investigation, Visualisation, Writing – original draft, Writing – review and editing. **Claire M Rickard**: Conceptualisation, Methodology, Writing – original draft, Writing – review and editing. **Nicole Marsh**: Conceptualisation, Methodology, Writing – original draft, Writing – review and editing.

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None.

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