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Systematic Review

The burden of healthcare-associated infection in Australian hospitals: A systematic review of the literature

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Abstract *Introduction:* Central to all efforts to control and prevent healthcare associated infections (HAIs) is the inherent need to measure the burden of infection and disease, classically referred to as surveillance. Australia does not have a national HAI surveillance system making it very difficult to systematically assess and report on the burden of hospital-acquired HAIs. This systematic review reports the incidence burden of HAIs in Australian hospitals as reported in the peer-reviewed literature from 2010 to 2016.
Methods: Systematic review of the peer-reviewed literature reporting the incidence of HAIs in Australian hospitals between from 2010 to 2016 was identified using MEDLINE and CINAHL databases. The study protocol is registered with PROSPERO (registration number: CRD42016052997).
Results: Of the 844 articles identified in the search, 24 articles were included in this review. Overall, these data suggest 83,096 HAIs per year in Australia, comprising 71,186 urinary tract infections, 4902 *Clostridium difficile* infections, 3946 surgical site infections, 1962 respiratory infections in acute stroke patients and 1100 hospital-onset *Staphylococcus aureus* bacteraemia. This is very large underestimate given the lack of or incomplete data on common infections such as pneumonia, gastroenterological and bloodstream infection, thus potentially missing up to 50%—60% of infections. If that is the case, the incidence of HAIs in Australia may be closer to 165,000 per year.
Conclusion: There is a dearth of peer-reviewed literature reporting the incidence of HAIs in Australian hospitals, making it very difficult to an accurate burden of infection. On the eve

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of a global 'post antibiotic era', the need for national consensus on definitions, surveillance methodology and reporting is paramount.

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Highlights

- This systematic review reports on the incidence burden of HAIs in Australian hospitals.
- There are approximately 165,000 HAIs occurring each year in Australia.
- There is a need for improved surveillance and reporting of HAIs in Australia.

Introduction

Healthcare-associated infections (HAIs) are a major patient safety issue in hospitals. While research into infection prevention and control has led to improvements in our understanding of effective HAI prevention strategies [1], HAIs continue to occur and lead to morbidity, mortality and excess healthcare expenditure [1,2]. Unlike most developed countries, Australia does not have a national system to monitor these infections and cannot provide an estimate of the burden of hospital-acquired HAIs. The last national point prevalence study conducted in Australia occurred in 1984 [3]. Healthcare delivery, technology and infection prevention and control initiatives have advanced considerably since this time.

In 2008, Cruickshank and Ferguson [4] estimated that there are about 200,000 HAIs each year in Australia, which if correct makes them the most common complication affecting patients in hospital. There has not been a subsequent evidence-based estimate of the incidence of HAIs in Australia despite HAIs being widely reported as the most common complication affecting patients in hospital globally. The purpose of this systematic review was to explore the burden of HAIs in Australian hospitals by determining the incidence of HAIs in Australian hospitals, as reported in the peer-reviewed literature from 2010 to 2016.

Methods

Protocol and registration

The protocol for this review is registered with PROSPERO, an international prospective register of systematic reviews (available at http://www.crd.york.ac.uk/prospero/ with registration number: CRD42016052997). Ethics approval was not sought because this review used data from published studies.

Search strategy

A systematic search was conducted using the electronic databases MEDLINE (PubMed) and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) to search for articles published between 1 January 2010 and 31 December 2016. The timeframe was chosen to include the most current HAI data. During the 2000s, a number of state and national initiatives were undertaken to reduce HAIs, including the national hand hygiene initiative, development of National Health and Medical Research Council guidelines, revision of hospital accreditation standards, surveillance initiatives and public reporting of some infection data [5–7]. Reference lists of eligible articles relating to these initiatives were reviewed to identify any additional articles.

To identify articles from MEDLINE and CINAHL, the search terms "surveillance", "incidence", "prevalence", "frequency", "rates or statistics" and "performance indicators" were used in combination with "nosocomial infection", "hospital acquired infection", "healthcare associated infection", "cross infection" and "infection". To identify and limit the search to articles from Australian hospitals, the search term "hospital" was used with "Australia", "Australian", "Queensland", "New South Wales", "Australian Capital Territory", "Victoria", "Tasmania", "South Australia", "Western Australia" and "Northern Territory". These terms were applied using an all text search. For the MEDLINE search, the MeSH terms "epidemiology", "cross Infection" and "disease transmission, infectious" were also used.

Inclusion criteria

Articles were eligible if they reported the results of cohort studies, case-control studies, cross-sectional studies, randomised controlled trials or case reports (reporting incidence) of HAI. For this study, cohort studies include studies where a population is followed up to determine whether they subsequently acquire an infection. To be eligible, data collection had to occur after 1 January 2010. Articles were limited to studies conducted in Australian hospitals. For international or multi-centre studies, data from Australian hospitals was included if the data was reported at this level. Where Australia-specific data was not available, the study was excluded.

Exclusion criteria

The following exclusion criteria applied: all grey literature, non-peer reviewed, conference abstracts, papers written in languages other than English, reviews, editorials, commentaries or policy statements.

Definitions

For this review, the definition of HAI used in the articles must have referenced a recognised standard such as a definition agreed or published by professional association or government agency, a definition widely used in the published literature or an ICD10 code that constitutes a HAI (not any infection). Any disputes about whether an article had used an appropriate definition were resolved by discussion among the reviewers.

Study selection

The titles and abstracts of the articles identified from MEDLINE and CINAHL were examined and assessed for relevance and appropriateness to the review question by one reviewer (CW). Those not relevant were excluded. For a random selection (10%) of articles, the abstracts were independently reviewed by another reviewer (BM) to identify any discrepancies; none were identified. Of the remaining articles, a full text review was undertaken (CW) to assess eligibility. Where there was uncertainty as to whether an article should be included, two researchers independently reviewed the articles (PR and RS). If there was disagreement, a third reviewer made the final determination (BM).

Data collection process

A data extraction form was developed for extracting data for the systematic review (Supplementary 1). All data items extracted were cross-checked. No attempt was made to contact the authors of papers that had missing data or unclear information.

Risk of bias

An assessment of study quality and risk of bias in the articles included in the review was conducted using the Newcastle—Ottawa Scale, as recommended by the Cochrane Collaboration [8,9]. The tool enables a maximum of nine stars to be awarded to a study. The content validity and inter-rater reliability of this tool has been established [9]. Two reviewers undertook this assessment independently (PR and RS). For any discrepancies, a third reviewer (BM) made the final determination. We were unable to determine level of bias associated with not including all HAIs in the review. Publications on the HAI incidence (or prevalence) varies considerably and includes the possibility of not publishing any data, not reporting on all HAIs a lack of sensitivity in HAI surveillance or methodological approaches used and a lack of validation. Such an issue is not limited to this study and is widespread in the area of HAI data, particularly in Australia [10—12].

Data analysis

All extracted data was entered into a comprehensive evidence-base table for descriptive analysis; 95% confidence intervals were calculated using Poisson regression. Meta-analysis was not performed due to the studies' heterogeneous methods, in particular, data collection. Meta-regression was not possible for the same reason.

Estimating the annual incidence of HAIs in Australia

We estimated the annual incidence of HAIs in Australia by extrapolating and modelling data from multi-centre studies that observed the same type of infection. Only multi-centre studies were used in the estimation, as they are likely to be more representative than single site studies. To estimate the annual number of cases of hospital onset *Staphylococcus aureus* bacteraemia and hospital identified *Clostridium difficile*, the total number of cases of each infection (identified in the included studies) was divided was divided by population data and subsequently multiplied by the Australian population. Population data was aggregate population of the states and territories contributing to the data. Population data for states territories and Australia was obtained from the Australian Bureau of Statistics, with 2016 population estimates used [13].

To calculate the estimated number of cases of respiratory infections and surgical site infections, the raw data from studies was recalculated (if not reported) to determine the incidence (number of cases/number of procedures surveyed $\times$ 100). Confidence intervals were also calculated. Where studies contained incidence data for more than one year, the data from the last reported year in the study was used for modelling to ensure the most recent data was used. If incidence data was not reported by year, the incidence for the entire study period was used for modelling.

Data from the Australian Institute of Health and Welfare and the Australian Commission on Safety and Quality was used to determine the number of procedures performed each year in Australia [14—17]. The calculated incidence was multiplied by the number of reported procedures per year, to give an estimated number of cases per year in Australia.

The number of healthcare associated urinary tract infections was reported as an incidence per 100 patient admissions in the literature. To determine the number of patient admissions per year in Australia, separation data from the Australian Institute of Health and Welfare was used [16]. Overnight separations are the closest available denominator to patient admissions. The reported incidence in the literature was multiplied by the number of overnight separations, to provide an estimated number of cases per year in Australia.

Results

Study selection

The initial database search identified 843 articles, with one additional article identified through hand searching. After duplicate articles were removed, 751 abstracts were reviewed and 105 articles were deemed suitable for a full text review. Twenty-four studies met the eligibility criteria and were included in this review. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart describing the papers identified from the search strategy is presented in Fig. 1.

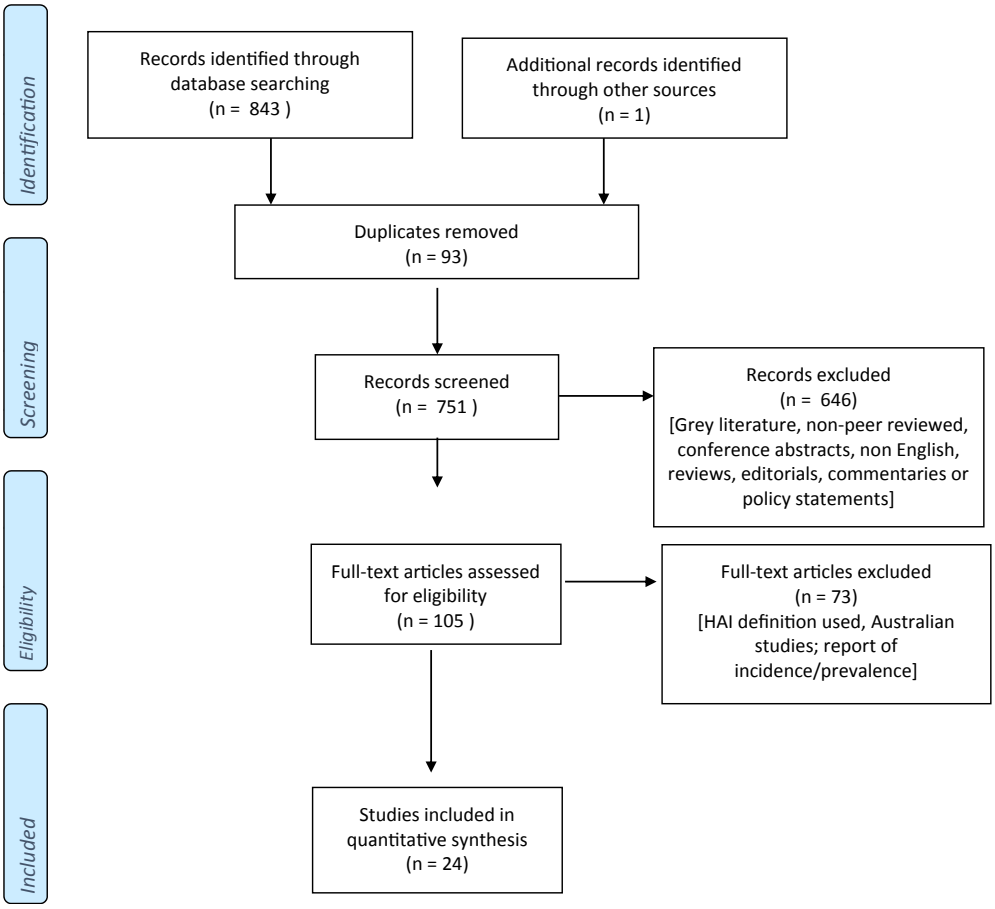

Figure 1 PRIMSA flow diagram for study selection.

Risk of bias

When studies were assessed for risk of bias using the Newcastle—Ottawa scale, the number of stars awarded to studies ranged from five to eight, the median being seven.

Study characteristics

A summary of the included articles with an overview of their key characteristics is provided in Table 1. Of the 24 included articles, the most common infections surveyed were bloodstream infections (eight articles), surgical site or procedure infections (six articles) and respiratory infections (four articles). *C. difficile* infection was reported in three articles, with the remainder reporting multiple or other infections. There was variation in the methodological approaches used to identify infections, the definitions used to determine an infection, the patients included in the studies and the number of hospitals involved. Four of the articles involved hospitals in more than one state. Eight articles involved hospitals from Victoria only, making this state the most represented.

Results by type of infection

Bloodstream infection

Four of the eight articles reported bloodstream infections at a hospital level; the remainder examined either bloodstream infections within an intensive care unit or patients who were undergoing a procedure. There was further variation in the types of bloodstream infections surveyed, with *S. aureus* bacteraemia the most common. There was some consistency in the methods used to determine the incidence of *S. aureus* bacteraemia. The reported incidence of hospital-acquired *S. aureus* bacteraemia was 0.77 per 10,000 bed days from New South Wales hospitals and 1.33 per 10,000 bed days from Queensland hospitals [18]. Mitchell et al. reported an incidence of 0.90 per 10,000 bed days for hospital-onset *S. aureus* bacteraemia [19], but did not include hospitals from New South Wales, Queensland or Victoria. In this study by Mitchell et al. [19], hospital-acquired *S. aureus* bacteraemia was defined as a *S. aureus* bacteraemia occurring more than 48 h after admission, whereas the article based on New South Wales and Queensland data used these criteria in addition to

Table 1 Overview of study findings.

Lead author	Location (no hospitals)	Hospital type	Data collection	Infection type	Population	Process	Key results	Definitions
Bloodstream infections								
Alcorn [20]	QLD (1)	Principal referral	2001—2011	Bloodstream infection (BSI)	All hospital	Retrospective	All: 841/10,000 overnight discharges Gram negative: 7.8/10,000 Gram positive: 12.6/10,000	AUS
Anderson [21]	NSW (1)	Private	2009—2013 (5 years)	Bacteraemia following TRUS biopsy.	One surgeon's patients	ICD, data warehouse & chart review.	1.5% (71 patients) bacteraemia over 5 years.	EST
Aubron [22]	VIC (1)	Principal referral	2006—2011 (6 year)	BSI associated with positive ICU-acquired positive urine culture	ICU	Retrospective	Candiduria 3.5 episodes/1000 ICU day Bacteriuria 2.8 episodes/1000 ICU day	COM
Coombs [24]	All (29)	Various	2011	*S. aureus* bacteraemia	All hospital, only first 100 collected	Laboratory based. Period prevalence.	MRSA accounted for 30.3%, 2357 isolates.	COM
Mitchell [19]	WA, SA, TAS, ACT (132)	Various		*S. aureus* bacteraemia[1]	All hospital	Prospective	0.90/10,000 patient days (95% CI 0.86—0.93)	COM
Mumford [41]	NSW (77)	Various	2009—12	*S. aureus* bacteraemia[2]	All hospital	Retrospective	Peer group A = 1.52 per 10,000 bed days Peer group B = 0.93 per 10,000 bed days Peer group C = 1.06 per 10,000 bed days Peer group D = 0.62 per 10,000 bed days All (2012) = 0.77 per 10,000 bed days	AUS
Si [18]	QLD (23)	Various	2008—12	*S. aureus* bacteraemia[1,2]	All hospital	Prospective	Inpatient BSI 6.0/10,000 patient days Inpatient, intravascular associated: 1.9/10,000 patient days Inpatient, *S. aureus* bacteraemia 1.0/10,000 patient days HCA *S. aureus* bacteraemia 1.3/000 patient days[a]	AUS
Wong [23]	VIC (1)	Principal referral	2008—2014 (5 years, 10m)	ICU-acquired central line-associated bloodstream infection (CLABSI)	ICU	Retrospective	ICU-acquired CLABSI 1.1 per 1000 ICU CVC-days	INT
Surgical site/procedure related								
Chandrananth [25]	VIC (3)	Unknown	2011—2014 (3 year)	Surgical site infection	Hip or knee arthroplasty.	Retrospective	2.7% infection rate	INT

(*continued on next page*)

Table 1 (*continued*)

Lead author	Location (no hospitals)	Hospital type	Data collection	Infection type	Population	Process	Key results	Definitions
Phan [42]	ACT (1)	Principal referral	2007—2010	External ventricular drains infection	Patient with external ventricular drains	Retrospective	13 infections from 114 patients (11.5%)	CLIN
Roth [28]	VIC (311)	Various	2007—2012	Infective complication following TRUS biopsy	Patients post TRUS biopsy	Victorian Admitted Episodes Data Set	1.73%, 95% (Cl 1.63—1.92%) readmitted with infection (604 of 34,865 patients).	CLIN
Tao [26]	VIC (1)	Principal referral	2012 (1 month)	Surgical site infection	Orthopaedic patients	Retrospective	7% surgical site infection. 95 procedures (6 superficial. 1 deep)[b]	INT
Worth [27]	VIC (81)	Various	2002—15	Surgical site infection	All hospital	Prospective	2.8 per 100 procedures surgical site infection. (95% CI 2.7—2.9). 5123 infections from 183,625 procedures. - 53.5% super-ficial - 23.6% deep incisional - 22.9% organ/space infections Coronary artery bypass surgery = 4.9/100 procedures (1137/23,108) Caesarean section = 2.0/100 procedures (1044/50,833) Hip/knee = 2.6/1000 procedures (1453/56,503) Colorectal = 8.6/100 procedures (753/8688) Other abdominal = 2.6/100 procedures (290/10,993) Cardiac non coronary artery bypass surgery = 3.8/100 procedures (133/3458) Hysterectomy = 2.0/100 procedures (131/6504) Vascular = 11.8/100 procedures (48/407)	INT
Ezzatzadegan [43]	NSW (1)	Principal referral	2000—2010 (10 years)	Invasive fungal infection	Renal transplant recipients	Retrospective	2.1%, 95% (CI 0.7%—3.4%) (10/471 patients)	CLIN
Respiratory								
Brogan [29]	NSW (6)	Principal referral	2010	Respiratory infections in acute stroke.	Stroke patients	Retrospective	11.3 % (60/(533 patients))	NS
Gautam [44]	NSW (1)	Principal referral	(1 year)	Ventilator-associated	paediatric intensive care	Prospective observational	7.02/1000 ventilation days (18 episodes/269 patients)	INT

				pneumonia	unit:			
Macesic [30]	All (15)	Various	2010–11	Hospital-acquired influenza	All hospital	Sentinel	4.3% of cases were nosocomial. (26/598 cases)	CLIN
Sanagou [31]	NS (16)	Various	2001–2011	HCA pneumonia post cardiac surgery.		Retrospective (registry)	5.1% (2229 cases/43,691 patients)	
C. difficile								
Foster [32]	WA (2)	Principal referral	2011–12 (6 months)	*C. difficile* infection	All hospital	Retrospective	Hospital 1 = 6.8 cases/10,000 OBDs Hospital 2 = 8.0 cases/10,000 OBDs. 53.8% of cases were hospital-onset.[c]	AUS/INT
Slimings [33]	TAS, VIC, NSW, QLD, SA, WA, ACT (450)	Various	2011–12	*C. difficile* infection	All hospital	Prospective	Hospital identified: 3.65 (95% CI 3.58–3.71) per 10,000 patient days (12,683 cases/34786323 patient day) Hospital associated 2.95 (95% CI 2.86–3.04) per 10,000 patient days (WA, SA, ACT,TAS, VIC only. 6759 cases/5,585,533 patient days)	AUS
Worth (2016) [34]	VIC (136)	Various	2010–2014	*C. difficile* infection	All hospital	Prospective	Healthcare associated 2.49 cases per 10,000 occupied bed days. (4826 cases)	INT
All other								
Jarratt [46]	SA (1)	Private hospital	2003–2011 (9 years)	HCA infections (various)	All hospital (>18 years)	Retrospective	1017 HAIs ~0.63% of all patients admitted to the hospital	CON
Mathot [45]	VIC (1)	Children	2002–12 (11 years)	Bacteraemia and pneumonia	Paediatric ICU	Prospective	8.9% patients had serious bacterial infections (blood culture or bronchial alveolar lavage) (881 of 9947 patients)	CLIN
Mitchell [35]	NSW (8)	Various		Urinary tract infection[1]	All hospital	Retrospective	1.73% (96% CI 1.67–1.80) of admitted patients. (2821/162,503 patient admissions)	EST

Note: HCA = healthcare associated. BSI = bloodstream infection. ICU = intensive care unit. TRUS = transrectal ultrasound. ICD = International Statistical Classification of Diseases and Related Health Problems. WA = Western Australia. SA = South Australia. ACT = Australian Capital Territory. TAS = Tasmania. NSW = New South Wales. QLD = Queensland. MRSA = Methicillin resistant *S. aureus* AUS = Consistent with Australian or nationally used/agreed definition. INT = Consistent with national Healthcare Safety Network (NHSN) and or Centres for Disease Control definitions. EST = consistent with an established or previously documented definition (for example, professional association). NS = Not stated. COM = Common approach to defining a healthcare associated infection – consistent with not incubating on admission and or acquired 48 h after admission. CLIN = defined as an infection based on clinical grounds, assessment or review of notes. [1]Hospital onset. [2]Healthcare associated.

[a] Calculated from available data.

[b] Unadjusted rate/not risk adjusted.

[c] Unable to determine combined incidence from available data.

other criteria. The combined incidence of hospital-acquired *S. aureus* bacteraemia was 0.93 cases per 10,000 bed days (95% CI 0.90—0.96) [18,19]. Other articles reporting bloodstream infection rates were limited to one hospital [20—23] or did not report the incidence of bloodstream infection [24].

Surgical site or procedure related infection

Three studies reported the incidence of surgical site infection in orthopaedic patients [25—27], but only two of these reported rates at a procedure level [25,27]. Both of these studies included hospitals from Victoria and had overlapping study periods. In addition to these studies, Roth et al. [28] undertook a multi-centre study to determine the incidence of infectious complications following trans-rectal ultrasound. This study examined data from 31,209 patients from public and private hospitals over a five-year period and found that 1.73% of these patients were readmitted with a biopsy-related infection [28].

Respiratory

The articles that reported respiratory HAI were heterogeneous in terms of the type of infections, the participants monitored and the methodological approaches used. Three were multi-centre studies but reported on different HAI: respiratory infections in acute stroke patients [29], influenza [30] and pneumonia following cardiac surgery [31].

***C. difficile* infection**

Three multi-centre studies examined *C. difficile* infection with overlapping data collection periods [32—34]. The study by Slimings et al. [33] was conducted in seven Australian states and territories and involved 450 public hospitals. The incidence of hospital-identified *C. difficile* infection was 3.65 per 10,000 bed days, while the incidence of hospital-associated *C. difficile* infection was 2.95 per 10,000 bed days (from five states and territories). This finding is consistent with that of Worth et al. [34], who examined *C. difficile* infection in 136 healthcare facilities over a four-year period and found the incidence of healthcare-associated *C. difficile* infection to be 2.49 cases per 10,000 bed days. From the published data, we were unable to calculate the incidence of healthcare-associated *C. difficile* infection in the study undertaken in Western Australia [32].

Other

Three studies examined other HAI but only one study was multi-centre [35]. In this study examining the incidence of healthcare-associated urinary tract infections in eight hospitals over a four-year period, the authors found that 1.7% of admitted patients acquired a HAI of the urinary tract.

Estimates of yearly HAI incidence

Using data from multi-centre studies, we sought to estimate the number of HAI occurring each year in Australia (Table 2). From the available data, we estimate 83,096 HAIs occur each year in Australia, however this number is a significant underestimation, it was only based on peer-reviewed published multi-centre studies Included in our review. The 83,086 HAIs comprised of 71,186 urinary tract infections, 4902 healthcare associated *C. difficile* infections, 3946 surgical site infections, 1962 respiratory infections in acute stroke patients and 1100 hospital onset *S. aureus* bacteraemia infections.

Discussion

This paper presents the first systematic review of Australian HAI rates published in the peer-reviewed literature. We identified 24 studies published between 2010 and 2016. The infections surveyed, their definitions and the methods used varied considerably. To understand the magnitude of HAIs and associated burden of disease in Australia more fully, we attempted to estimate the incidence of HAIs using data from multi-centre studies.

A previous report estimated the incidence of HAIs in Australia to be 177,392 HAIs per year (headline number of 200,000 HAIs) [4]. This estimate was made several years ago and was based on one study conducted in one hospital; the best available data at that time. Unfortunately, the evidence base for estimating the incidence of HAIs in Australia remains lacking, certainly when using data from the peer-reviewed literature. Our review has highlighted a myriad of different approaches to measure and define HAIs. In many instances, the data presented was limited, making comparisons or extrapolation of data impossible. In the absence of a national system for reporting there is a real need for those undertaking HAI surveillance — both at a hospital and a state level — to publish HAI surveillance data in the peer-reviewed literature. Accessing such information from government websites is fraught with challenges, including lack of detail about methods, delays in publishing data or failure to publish data. These issues do not apply to all states and territory health departments, but there are significant gaps across the country. This was also reflected in the results of our literature review, where more articles were published from Victorian data than any other state. Limited data is available from other states or on the MyHospitals website (www.myhospitals.gov.au).

National point prevalence studies are undertaken periodically in numerous countries including the United States, Canada and all European countries [2,36,37]. Australia is one of the few Organisation for Economic Co-operation and Development countries that does not undertake national HAI point prevalence studies, or have a national surveillance program [10]. These studies provide valuable insights into the most frequent HAIs: gastroenterological, respiratory, surgical site and urinary tract. Our review has identified few studies that explored the incidence of gastroenterological and respiratory infections, despite these being the most common. Surgical site infection data was well represented from studies from Victoria and urinary tract infection from New South Wales [26—28,35]. The data included in our review misses a large proportion of HAIs due to the absence of published incidence data.

Using data from the multi-centre studies to improve representativeness, we estimated the incidence of some types of HAIs. We estimate that each year in Australia, there are 71,186 urinary tract infections, 4902 *C. difficile* infections, 3946 surgical site infections, 1962 respiratory

Table 2 Multi-centre studies and estimates of healthcare-associated infections in Australia.

Infection	Lead author	Data extracted or recalculated from studies for model	Estimated denominator.-	Modelled number of cases in Australia each year
Bloodstream infection				
Hospital onset *S. aureus* bacteraemia	Mitchell [19]	253 cases in WA, SA, ACT, TAS in 2012.	5.24 million population	1100 cases per year (95% CI 995—1193)
	Si [18]	207 cases from QLD in 2012.	4.84 million population.	
Healthcare associated *S.aureus* bacteraemia	Mumford [41]	0.77 (SD 0.77)		Unable to model[a]
			Subtotal	1100
Surgical site infection				
Hip and knee	Worth [27]	2.57/100 procedures (95% CI 2.44—2.71)	25,938 procedures/year.	Hip/knee = 667 cases[b,c] (Public hospitals)
	Chandrananth [25]	2.75/100 procedures (95% CI 1.86—3.9)ˆ		
Coronary artery bypass surgery	Worth [27]	4.51/100 procedures (95% CI 2.72—7.05)	3837 procedures/year.	189 cases[c] (Public hospitals)
Caesarian section	Worth [27]	2.75 (95% CI 2.26—3.32)	95,894 procedures/year.	1969 cases[c] (All hospitals)
Hysterectomy	Worth [27]	2.01 (95% CI 1.68—2.39)	9989 procedures/year.	201 cases[c] (Public hospitals)
Vascular	Worth [27]	11.79 (8.70—15.64)	4002 procedures/year.	472 cases[c,d] (Public hospitals)
Infective complication following TRUS biopsy	Roth [28]	1.73%, (95% Cl 1.63—1.92%) readmitted with infection	25,869 procedures/year.	448 cases (All hospitals)
			Subtotal	3946
Respiratory				
Respiratory infections in acute stroke	Brogan [29]	11.3% (95% CI 8.7—14.4%) of patients	15,684 cases on hospital per year	1766 cases[e] (All hospitals)
Influenza	Macesic [30]	4.5% (95% CI 2.9—6.3%)ˆ		Unable to model[a]
Pneumonia post cardiac surgery.	Sanagou [31]	5.1% (95% CI 4.9—5.3%)ˆ	3837 procedures/year.	196 cases (Public hospital)
			Subtotal	1962
Other				
C. difficile infection (healthcare associated)	Slimings [33]	2.95 (95% CI 2.86—3.04) per 10,000 patient days. 2298 cases from WA, SA, AC, VIC and TAS.[#]	11.3m population.	4902 cases per year[f]
C. difficile infection (healthcare associated)	Worth [34]	2.49 cases per 10,000 OBDs +		

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Table 2 (*continued*)

Infection	Lead author	Data extracted or recalculated from studies for model	Estimated denominator.-	Modelled number of cases in Australia each year
Healthcare associated urinary tract infection	Mitchell [35]	1.73% (95% CI 1.67—1.80) of admitted patients	4.1m overnight separations per year[g]	71,186 cases (95% CI 68,481—73,812) (All hospitals)
			Subtotal	76,088
			Total	**83,096**

Notes: WA = Western Australia. SA = South Australia. ACT = Australian Capital Territory. TAS = Tasmania. TRUS = transrectal ultrasound biopsy. ^ 95% CI calculated from data provided in the original study.-Estimated denominators as based on the best available data from the Australian Bureau of Statistics, Australian Institute of Health and Welfare and the Australian Commission on Safety and Quality in Healthcare. + 95% CI could not be calculated from data provided in the original study. # 2298 cases calculated from data a reported incidence of 2.95 per 10,000 bed days (4597 cases over two years) from WA, SA, ACT, VIC and TAS.

[a] Insufficient data published in the study (numerator and or denominator).
[b] Data from Worth et al. [27] only used. Data collection from Chandrananth et al. [25] overlaps and may include the same hospitals.
[c] Unadjusted number of infections.
[d] Based on a denominator of the number of varicose veins procedures in one year. Only available data.
[e] Based on a denominator of cerebral infarction and stroke ischaemic hospital data.
[f] Data from Slimings et al. [33] only used. Data collection from Worth et al. [34] overlaps.
[g] Overnight separations used as the closest denominator to patient admissions.

infections in acute stroke patients and 1100 *S. aureus* bacteraemia. These total 83,096 HAIs each year, but would be a very large underestimation given the lack of data on common infections. These estimates also come with considerable caveats due to the different methodologies and definitions. In the only national data available, our estimates for *S. aureus* bacteraemia are broadly consistent with that reported by the Australian Institute of Health and Welfare, who report 1440 cases of healthcare associated *S. aureus* bacteraemia in the 2015—16 financial year [38]. The difference is likely explained by case definitions (hospital onset Vs healthcare associated).

Data from the United States and Europe suggests that pneumonia accounts for 21.8%—25.7% of HAIs: 7.8%—17.1% are gastroenterological infections, 9.9%—14.2% are bloodstream infections, and 3.1%—5.6% are ear, nose and throat infections [2,36]. Our review only had data on the incidence of pneumonia from one group of patients (post-stroke) and one bloodstream infection (*S. aureus* bacteraemia). *C. difficile* infection was the only gastroenterological infection included in our review and we had no data on ear, nose or throat infections or many other HAIs such as central nervous system, reproductive tract and skin and soft tissue infections. Therefore, our estimate of 83,096 infections does not take into account a large proportion of pneumonia, gastroenterological, bloodstream infection or other infection data, thus potentially missing up to 50%—60% of infections. If that is the case, the incidence of HAIs in Australia may be closer to 165,000 per year.

One limitation of our review was that we did not source grey literature, specifically HAI data published on state and territory government websites. These data are difficult to locate, are reported differently and often used methodology that is not adequately described in an open forum. We recommend a follow-up review, focussing on collating and analysing this data. This approach was outside the scope of our review and available resources, and should be undertake in a future review.

Having a reliable estimate for the incidence of HAIs is important for a number of reasons. First, in an era of finite health resources, it helps prioritise infection prevention and control strategies. Second, it provides a benchmark against which future achievements or targets can be measured and evaluated. Third, it enables industry and those involved in healthcare innovation to have more reliable data for investment in products and research. Finally, it helps determine the resources required for HAI prevention and control relative to other health issues. On the eve of a global 'post-antibiotic era' [39], the need for coordinated and systematic national surveillance and reporting of HAIs and established contributing factors, namely antimicrobial resistance and antibiotic usage, has never been greater.

We believe three concurrent strategies are required to address this gap. There needs to be a determination and action by state and national government bodies to achieve consensus on definitions, approaches to surveillance and transparent regular reporting. This should happen in parallel to the establishment of a national HAI surveillance program. There have been calls for a national centre for disease control [40], potentially a national HAI surveillance program could be incorporated into such a centre. Finally, a

national point prevalence study would provide valuable insight in the short term on the burden of HAIs in Australia. Given that the latter does not require a sophisticated study design and provides descriptive results, it has not been favourably supported by funding bodies. Whilst these suggested strategies have to date failed to eventuate, we call on all those involved in undertaking HAI surveillance in Australia to work collaboratively and publish data in the peer-reviewed literature.

Authorship statement

BM and PR conceived the study and drafted the research protocol. BM, PR, RS and DM provided critical review of and approved the study design. BM conducted the database searches. CW made the primary selection of eligible papers including data extraction. BM, PR and RS supervised and checked the study selection process and data extraction. BM analysed the data. All authors contributed to interpretation of the analysis. BM and CW wrote the manuscript. All authors provided critical review and approved the final manuscript.

Conflicts of interest

BM, PR and DM were authors on some of the included papers in this review. The decision to include/exclude studies which they authored, in addition to a risk of bias assessment was made independently by other members of the research team. All data extracted from these studies were independently checked by other members of the research team. The authors have no other conflicts to declare.

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Provenance and peer review

Not commissioned; externally peer reviewed.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.idh.2017.07.001.

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