Intensive Care Med (2013) 39:1080–1087
DOI 10.1007/s00134-013-2841-z

ORIGINAL

Katie Harron
Angie Wade
Berit Muller-Pebody
Harvey Goldstein
Roger Parslow
Jim Gray
John C. Hartley
Quen Mok
Ruth Gilbert

Risk-adjusted monitoring of blood-stream infection in paediatric intensive care: a data linkage study

Received: 25 September 2012
Accepted: 12 January 2013
Published online: 12 February 2013

K. Harron (✉) · A. Wade · H. Goldstein · R. Gilbert
MRC Centre for Epidemiology of Child Health, Institute of Child Health, University College London, 30 Guilford Street, London WC1 N 1EH, UK
e-mail: k.harron@ich.ucl.ac.uk; k.harron@ucl.ac.uk
Tel.: +44-207-9052764
Fax: +44-207-9052793

B. Muller-Pebody
Healthcare Associated Infection and Antimicrobial Resistance Department, Health Protection Agency, London, UK

R. Parslow
Paediatric Epidemiology Group, University of Leeds, Leeds, UK

J. Gray
Department of Microbiology, Birmingham Children's Hospital, Birmingham, UK

J. C. Hartley
Department of Microbiology, Virology and Infection Prevention and Control, Great Ormond Street Hospital, London, UK

Q. Mok
Paediatric Intensive Care Unit, Great Ormond Street Hospital, London, UK

Abstract *Purpose:* National monitoring of variation in the quality of infection control in paediatric intensive care units (PICUs) requires comparisons of risk-adjusted rates. To inform the development of a national monitoring system, we evaluated the effects of risk-adjustment and outcome definition on comparisons of blood-stream infection (BSI) rates in PICU, using linkage of risk-factor data captured by national audit (PICANet) with laboratory records of BSI. *Methods:* Admission data for two children's hospitals 2003–2010 were extracted from PICANet and linked using multiple identifiers with laboratory BSI records. We calculated trends of PICU-acquired BSI, defined as BSI occurring between at least 2 days after admission until up to 2 days following discharge. In one PICU, we compared rates of all PICU-acquired BSI with clinically significant PICU-acquired BSI submitted to the national surveillance system. *Results:* Of 20,924 admissions, 1,428 (6.8 %) were linked to 1,761 PICU-acquired BSI episodes. The crude incidence rate-ratio for PICU-acquired BSI between PICUs was 1.15 [95 % confidence interval (CI) 1.05–1.26] but increased to 1.26 (1.14–1.39) after risk-adjustment. Rates of PICU-acquired BSI were 13.44 (95 % CI 12.60–14.28) per 1,000 bed-days at PICU 1 and 18.05 (95 % CI 16.80–19.32) at PICU 2. Of PICU-acquired BSI at PICU 2, 41 % was classified as clinically significant. Rates of PICU-acquired BSI decreased by 10 % per year between 2003 and 2010 for skin organisms and 8 % for non-skin organisms. *Conclusions:* Risk-adjustment and standardisation of outcome measures are essential for fair comparisons of BSI rates between PICUs. Linkage of risk-factor data and BSI surveillance is feasible and could allow national risk-adjusted monitoring.

Keywords Blood-stream infection · Surveillance · Data linkage · Paediatric intensive care · Risk-adjustment · Bacteraemia

Introduction

Healthcare-associated infection (HAI) is an important cause of adverse clinical outcome and cost to the UK National Health Service (NHS), and paediatric intensive care units (PICUs) have one of the highest reported rates of nosocomial blood-stream infection (BSI) of any clinical specialty [1–4]. Interventions aimed at reducing HAI

have succeeded in dramatically decreasing rates of infection in the US and have led the way for similar interventions in the UK, including the introduction of the Department of Health Saving Lives CVC care bundle in 2005 [5–8].

Monitoring of infection outcomes is vital for determining the impact of these interventions and for sustaining improvements in practice [9, 10]. Comparison of healthcare associated BSI rates and assessment of variation of quality of care between PICUs would allow improved practices to be targeted at those most likely to benefit.

Reliable risk-adjustment is required for meaningful comparisons between PICUs [11]. At a national level, no single dataset accurately captures both clinical and microbiological BSI data [12]. LabBase2 is a national voluntary microbiological surveillance database collated by the Health Protection Agency (HPA), based on clinically significant isolates identified at laboratories serving NHS hospitals [13]. The Paediatric Intensive Care Audit Network (PICANet) collects data on all children admitted to PICUs in Britain, including clinical details such as diagnosis and morbidity score on admission [14]. Linkage of these existing datasets offers an efficient method for providing risk-adjusted national surveillance.

To demonstrate the effect of risk-adjustment using routinely collected data and the importance of standardised outcome measures, we linked PICANet data with microbiology data from two large UK PICUs, to assess reductions in BSI acquired within PICU.

Methods

Data and case definition

Admission data for all children admitted to Birmingham Children's Hospital (BCH) PICU (General and Cardiac) and Great Ormond Street Hospital (GOSH) PICU (General and Cardiac) between March 2003 and December 2010 were extracted from the PICANet database. Variables extracted for analysis were admission and discharge dates, Paediatric Index of Mortality (PIM2) score at admission, age, sex, admission type (planned or unplanned), admission source (same hospital or elsewhere), primary diagnosis at admission [based on primary diagnosis coded with the International Classification of Disease (ICD10)], and variables indicating renal support and mechanical ventilation [15].

BCH and GOSH laboratories routinely record microbiology data for all bacterial isolates from blood culture. From these laboratory systems, we extracted data on all positive isolates for children admitted to hospital between March 2003–2010, regardless of whether they were considered contaminants or clinically significant.

We defined an episode of BSI as any positive blood culture with:

1. One or more organisms isolated from any blood sample taken on the same day
2. Repeated samples with positive cultures of the same organism within 14 days

A child could have more than one BSI episode during an admission if different organisms were isolated on different days, or if the same organism was isolated on more than 1 day (>14 days apart).

We defined PICU-acquired BSI as any BSI from samples taken up to 2 days after discharge from PICU, but excluding samples taken on the day of admission or the day after admission to PICU. As laboratory records included the date but not the time the specimen was taken, some included samples may have been taken between 24 and 48 h after admission to PICU, thereby possibly resulting in a slight overestimation of rates. Laboratory data after discharge from PICU was available for the majority of children (81 %) as they were discharged to another ward within the same hospital.

We separately analysed PICU-acquired BSI due to skin and non-skin organisms, as we hypothesised that infection control practices might have more impact on BSI due to skin organisms, which can be acquired during invasive procedures or sample contamination [16, 17]. Skin organisms were defined as coagulase negative staphylococcus, *Staphylococcus epidermidis, Corynebacterium* spp. or *Proprionibacterium* spp. All other organisms were classified as non-skin organisms. PICU-acquired BSI episodes could include either skin organisms, non-skin organisms, or both, and so the number of episodes of PICU-acquired BSI due to skin organisms and due to non-skin organisms does not add up to the total number of episodes. We separately analysed PICU-acquired BSI in children staying at least 48 h to account for any differences in the number of very short-term admissions (with a lower risk of infection) between PICUs.

We assessed the effect of different case definitions for BSI reporting. The national voluntary surveillance system LabBase2, coordinated by the HPA, requires reporting of clinically significant BSI. At one of the two laboratories, an additional variable indicated positive BSI that had been considered to be clinically significant and were reported to LabBase2, based on prospectively recorded consultant microbiologist opinion following regular meetings with the clinical team and with reference to the CDC/NHSN definition of laboratory-confirmed bloodstream infection [18]. At the other laboratory, no classification of clinically significant BSI was available.

Data linkage

We generated our dataset by deterministic linkage of PICANet and microbiology records based on unique identifiers (NHS number, hospital number, name, date of birth and sex). Linkage was manually verified to ensure there were no false matches or missed matches.

Statistical analysis

PICU-acquired BSI rates were calculated as the number of PICU-acquired BSI per 1,000 bed-days. Because of the low event rate, we assumed a log-linear trend and fitted Poisson regression models[1] to the data, with length of stay (in hours) as the exposure variable. Model fits were compared using Akaike's Information Criterion, goodness of fit tests and likelihood-ratio tests for nested models. Models with best-fit were used to identify significant risk-factors for PICU-acquired BSI from the patient characteristics extracted from PICANet (Table 1). For these models, the quarter-year of admission, age in months, and PIM2 score were treated as continuous variables. Quarter of year (3-month calendar period), sex, admission type, admission source, renal support, mechanical ventilation and diagnosis group (cardiovascular, respiratory, infection or other) were categorical variables. We aimed to evaluate how relatively simple risk-adjustment affects comparative measures rather than to inform direct comparisons between PICUs, as BSI risk-factors were limited within our data. A PICU-year interaction term was added to the model to test for differences in trends between PICUs. The two PICUs were randomly coded as PICU 1 and PICU 2 so that individual units were not identified (same coding used throughout analysis) and to deter erroneous conclusions about relative performance.

Incidence rate ratios (IRR) with 95 % confidence intervals (CI) were derived from models of best fit and used to compare rates between PICUs. Risk-adjusted rates were derived for each PICU by adjusting for all risk-factors found to be significant in the Poisson regression. Kernel density estimates of rates were estimated for graphical display.

The time to infection was calculated as the number of days between admission and the date of PICU-acquired BSI. Cox proportional hazards models were fitted to the data to estimate the survival function for each PICU and to identify significant risk-factors for time to infection.

Analysis was performed using Stata 11 [19].

[1]Full model: $\log(\text{infections}) = \beta_1 \times \text{quarter-year of admission} + \beta_2 \times \text{PICU} + \beta_3 \times \text{admission type} + \beta_4 \times \text{diagnosis group} + \beta_5 \times \text{renal support} + \beta_6 \times \text{sex} + \beta_7 \times \text{age} + \beta_8 \times \text{PIM2} + \beta_9 \times \text{admission source} + \beta_{10} \times \text{mechanical ventilation} + \beta_{11} \times \text{quarter of year} + \log(\text{length of stay})$.

Table 1 PICANet data: characteristics of all children admitted to two PICUs in England, 2003–2010

	n admissions	%
Length of stay		
<48 h	9,059	43.29
>=48 h	11,865	56.71
Year of admission		
2003	2,361	11.28
2004	2,762	13.20
2005	2,423	11.58
2006	2,647	12.65
2007	2,638	12.61
2008	2,664	12.73
2009	2,936	14.03
2010	2,493	11.91
Quarter of year		
Jan–Mar	4,833	23.10
Apr–Jun	5,425	25.93
Jul–Sep	5,564	26.59
Oct–Dec	5,102	24.38
PICU		
PICU 1	12,310	58.83
PICU 2	8,614	41.17
Admission type		
Planned	8,583	41.02
Unplanned	12,341	58.98
Admission source		
Same hospital	12,772	61.04
Elsewhere	8,152	38.96
Diagnosis group		
Other	7,163	34.23
Cardiovascular	8,493	40.59
Respiratory	4,600	21.98
Infection	668	3.19
Renal support		
No	20,081	95.97
Yes	843	4.03
Mechanical ventilation		
No	16,195	77.4
Yes	4,729	22.6
Sex		
Female	11,813	56.46
Male	9,110	43.54
Unknown	1	0.00
Age group		
<1 year	11,347	54.23
1–4 years	4,839	23.13
5–10 years	2,611	12.48
11–15 years	2,127	10.17
Total	20,924	

Results

There were 13,376 records of bacterial isolates from blood culture dating between March 2003 and December 2010, inclusive, extracted from the microbiology systems at the two hospitals ($n = 5{,}589$ PICU 1, $n = 7{,}787$ PICU 2; hospital-wide). These corresponded to 6,842 episodes of BSI as defined in the case definition (hospital-wide).

Records for 20,924 admissions were extracted from the PICANet database for the two PICUs over the same time period, comprising a total of 117,800 bed-days (approximately 15,000 bed-days or 2,600 admissions per

year at the two PICUs combined). Table 1 shows the characteristics of the children admitted to the two PICUs between 2003 and 2010.

PICU-acquired BSI

A total of 1,761 PICU-acquired BSI episodes were linked to 1,428 admissions. Of these, 144 (8.2 %) BSI episodes included more than one type of organism isolated on the same day. Of these, 220 (15 %) admissions had multiple PICU-acquired BSI episodes during their stay in PICU.

The rate of PICU-acquired BSI per 1,000 bed-days was 15.17 (14.45–15.86) per 1,000 bed-days (Table 2). Quarter-year of admission, quarter of calendar year, age, admission type, admission source, renal support, PICU and diagnosis group were found to be significant at the 5 % level, but there was no evidence of an effect of sex, mechanical ventilation or PIM2 score on the rate of PICU-acquired BSI.

The crude IRR underestimated the difference between PICUs (1.15; 95 % CI 1.05–1.26) and the IRR increased to 1.26 (95 % CI 1.14–1.39) after adjusting for differences in significant risk-factors between PICUs. Although the median length of stay differed by PICU (70 and 48 h in PICUs 1 and 2 respectively), the exclusion of short-term admissions (<48 h, n episodes = 119) did not account for the difference between PICUs. The adjusted PICU IRR for admissions at least 48 h was 1.20 (95 % CI 1.08–1.33). The median time to PICU-acquired infection was 7 days from admission (95 % binomial CI 6–7). For any given time point, a greater proportion of children in PICU 2 had PICU-acquired BSI than in PICU 1, after adjusting for significant risk-factors [mechanical ventilation, age, PIM2, renal status, admission type, admission source, diagnosis group and quarter-year at admission (Fig. 1)]. Rates were lower in summer months.

The rate of PICU-acquired BSI decreased by 9 % (95 % CI 7–11 %) each year during the study period. This corresponded to a 44 % reduction (a reduction of 7.54 per 1,000 bed-days) in the rate of PICU-acquired BSI between 2003 and 2010. The percentage of admissions each year with PICU-acquired BSI decreased by 45 % over the study period (from 8.3 to 4.5 % of admissions). There was no evidence of a difference in trends between PICUs (p value = 0.43 for trend-PICU interaction).

Skin organisms and non-skin organisms

The rate of PICU-acquired BSI due to skin organisms was higher than the rate of PICU-acquired BSI due to non-skin organisms, and risk-factors for skin organisms differed to those for non-skin organisms (Table 3).

Rates of PICU-acquired BSI due to both skin organisms and due to non-skin organisms decreased between 2003 and 2010. As expected, there was a larger reduction seen in PICU-acquired BSI due to skin organisms (a 47 % reduction of 5.00 per 1,000 bed-days) compared with the

Table 2 Rate and risk-adjusted incidence rate ratios (IRRs) for PICU-acquired BSI

	PICU-acquired BSI		
Rate (95 % CI) per 1,000 bed-days		15.17 (14.45–15.86)	
% (95 % CI) of admissions with BSI		6.82 % (6.48–7.17 %)	
	n episodes	Incidence rate ratio (95 % CI)	p value
Year of admission		0.91 (0.89–0.93)	<0.001
Quarter of year			
Jan–Mar	472	1	
Apr–June	429	0.83 (0.73–0.95)	
Jul–Sep	410	0.83 (0.73–0.95)	
Oct–Dec	450	0.96 (0.85–1.10)	0.005
Age (months)		0.99 (0.99–0.99)	<0.001
PICU			
PICU 1	976	1	
PICU 2	785	1.26 (1.14–1.39)	<0.001
Admission type			
Planned	448	1	
Unplanned	1313	1.45 (1.28–1.64)	0.001
Admission source			
Same hospital	1,007	1	
Elsewhere	754	0.72 (0.65–0.80)	<0.001
Diagnosis group			
Other	632	1	
Cardiovascular	601	0.81 (0.72–0.92)	
Respiratory	441	0.77 (0.68–0.87)	
Infection	87	1.26 (1.01–1.59)	<0.001
Renal support			
No	1,482	1	
Yes	279	1.47 (1.29–1.68)	<0.001
Total	1,761		

IRRs were adjusted for all significant risk-factors listed in the table and the IRR for year of admission was converted from the IRR for quarter-year of admission

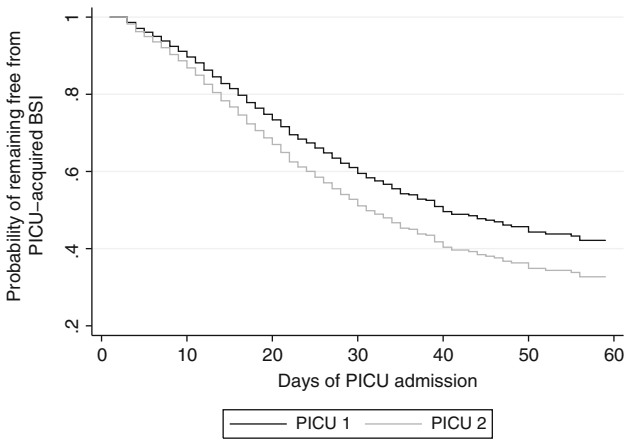

Fig. 1 Probability of remaining free from PICU-acquired BSI in first 60 days of admission by PICU, adjusted for mechanical ventilation, age, PIM2, renal status, admission type, admission source, diagnosis group and quarter-year at admission

decline due to non-skin organisms (a 34 % reduction of 2.64 per 1,000 bed-days). The percentage of admissions per year with PICU-acquired BSI due to skin organisms decreased by 52 % (from 5.8 to 2.81) compared with 41 % (from 3.6 to 2.1) due to non-skin organisms.

The difference between PICUs was due to differences in rates of non-skin organisms—there was no evidence of a difference in rates of skin organisms between PICUs (IRR = 1.10; 95 % CI 0.97–1.25). The crude IRR for non-skin organisms underestimated the difference between PICUs (1.38; 95 % CI 1.21–1.57), rising to 1.62 (95 % CI 1.41–1.85) after adjusting for differences in population at risk between PICUs. Figure 2 shows the risk-adjusted rate of PICU-acquired BSI due to skin organisms and non-skin organisms in each PICU.

Clinically significant BSI

Classification of BSI as clinically significant or not, based on prospectively recorded clinical opinion, was available for PICU 2. Of the 785 PICU-acquired BSI in this PICU, 321 (41 %) were classified as clinically significant. This was largely due the number of coagulase negative staphylococcus classified as not clinically significant—of the 445 PICU-acquired BSI due to skin organisms, only 155 (34.5 %) were clinically significant. However, a reduction in the number of non-skin organisms was also seen—of the 419 PICU-acquired BSI due to non-skin organisms, 284 (67.8 %) were clinically significant.

The rate of clinically significant BSI was 7.39 (95 % CI 6.58–8.18) per 1,000 bed-days, compared with an overall rate of 18.05 (95 % CI 16.80–19.32) for all PICU-acquired BSI at PICU 2 and 13.44 (95 % CI 12.60–14.28) at PICU 1.

Figure 3 shows the rate of clinically significant and overall PICU-acquired BSI at PICU 2.

Discussion

Our study demonstrates the importance of risk-adjustment and standardised outcome measures for monitoring of changes in BSI rates within and between PICUs. We show

Table 3 Rates and risk-adjusted incidence rate ratios (IRRs) of PICU-acquired BSI due to skin organisms and non-skin organisms

	Skin organisms			Non-skin organisms		
Rate (95 % CI) per 1,000 bed-days		9.29 (8.74–9.84)			7.37 (6.86–7.85)	
% (95 % CI) of admissions with >=1 specimen		4.62 % (4.34–4.92 %)			3.06 % (2.83–3.30 %)	
	n	Incidence rate ratio (95 % CI)	*p* value	*n*	Incidence rate ratio (95 % CI)	*p* value
Year		0.90 (0.87–0.93)	<0.001		0.92 (0.89–0.94)	<0.001
Quarter						
Jan–Mar	290	1		227		
Apr–June	266	0.83 (0.71–0.99)		212	Not significant	0.230
Jul–Sep	250	0.82 (0.69–0.97)		200		
Oct–Dec	272	0.96 (0.81–1.14)	0.0457	216		
Age (months)		0.99 (0.99–0.99)	<0.001		0.99 (0.99–0.99)	<0.001
Admission source						
Same hospital	595	1		513	1	
Elsewhere	483	0.75 (0.66–0.86)	<0.001	342	0.70 (0.60–0.81)	<0.001
PICU						
PICU 1	633	1		436	1	
PICU 2	445	1.10 (0.97–1.25)	0.134	419	1.51 (1.31–1.74)	<0.001
Admission type						
Planned	272	1		229	1	
Unplanned	806	1.39 (1.20–1.63)	<0.001	626	1.25 (1.04–1.51)	0.015
Diagnosis group						
Other	406	1		289	1	
Cardiovascular	338	0.70 (0.60–0.81)		310	0.87 (0.73–1.04)	
Respiratory	301	0.81 (0.70–0.94)		195	0.75 (0.62–0.90)	
Infection	33	0.75 (0.52–1.07)	<0.001	61	2.00 (1.52–2.66)	<0.001
Renal support						
No	921	1		709	1	
Yes	157	1.42 (1.19–1.68)	<0.001	146	1.53 (1.28–1.84)	0.001
Mechanical ventilation						
Yes	192	Not significant		180	1	
No	886			675	0.75 (0.63–0.90)	0.002
PIM2		Not significant			1.67 (1.08–2.57)	0.021
Total	1,078			855		

IRRs were adjusted for all significant risk-factors listed in the table

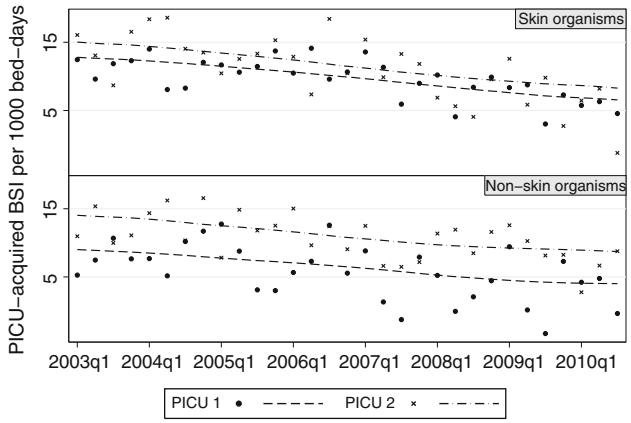

Fig. 2 Rates of PICU-acquired BSI due to skin organisms and non-skin organisms by PICU and quarter-year at admission, adjusted for quarter of year, admission type, admission source, age, renal support and diagnosis group. *Symbols* quarterly crude rates, *Lines* Kernel density estimate of risk-adjusted trends

that simple risk-adjustment can be achieved through linkage of routinely collected data. As variation between units is a key measure for monitoring the quality of care in PICU, these potential sources of bias need to be taken into account to ensure fair and accurate assessment of variation in outcomes [20].

This study spans a period when national and local guidance led to major changes in infection control and a near halving in rates of BSI. The dramatic reduction in PICU-acquired BSI rates seen from 2007, particularly in BSI due to skin organisms, corresponds to the introduction of the Saving Lives CVC care bundle [8]. These guidelines for insertion and maintenance of CVCs to prevent BSI led to the introduction of 2 % chlorhexidine swabs at GOSH and infection control audits of hand

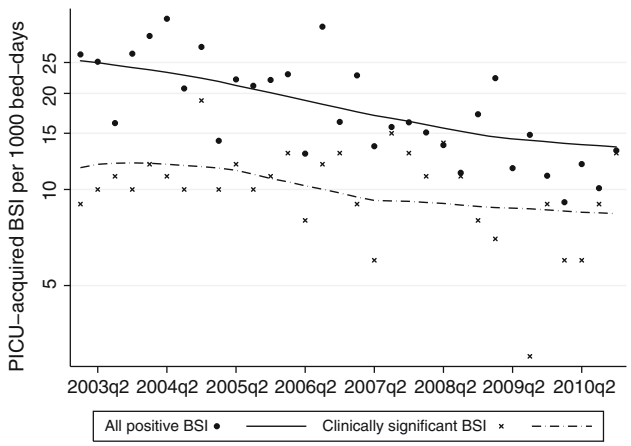

Fig. 3 Rates of clinically significant and all PICU-acquired BSI at PICU 2 by quarter-year at admission, adjusted for quarter of year, admission type, admission source, age, renal support and diagnosis group. *Symbols* quarterly crude rates *Lines* Kernel density estimate of risk-adjusted rates

hygiene and high impact interventions consistently scoring >90 % in BCH. This is the first study to link microbiology data with hospital admissions and to quantify this reduction in PICUs, though such changes are well recognised by clinicians [21].

Although there is broad recognition of the importance of risk-adjustment, current PICU risk-adjustment scores for mortality (PIM2) or indicators of severity of illness (renal support, mechanical ventilation) do not accurately capture all risk-factors for BSI. The overall difference in rates between PICUs did not appear to be due to skin-organisms, which are likely to correlate most closely with infection control practices. The variation in rates of PICU-acquired BSI due to pathogens may be due to differences in PICU casemix that are not routinely captured. More detailed risk-factor information may further explain variation between PICUs and improvements in routine data quality and methodology will allow a wider range of risk-factors to be explored. Use of information on trajectories of care preceding PICU admission using longitudinal hospital administrative data may enhance risk-adjustment [22–25].

We identified large differences between rates of total BSI and clinically significant BSI for both skin and non-skin organisms. Although definitions for classification of healthcare-associated BSI exist, there are no clear criteria to guide clinical judgement on classification of clinically significant positive isolates that are reported to the national surveillance system LabBase2 [26–28]. Clinicians need to make daily judgements for the care and treatment of patients, but national monitoring requires objective outcome measures to achieve fair comparisons. Automated downloads of laboratory data to the voluntary surveillance system, introduced in recent years, offer the opportunity to capture all positive BSI data. Analyses based on these data would overestimate the total burden of clinically significant BSI acquired in PICU, as in our study. However, it is also important to monitor contamination, as this may lead to overtreatment and possible increased length of stay in PICU. Measuring all positive BSI would ensure valid comparisons, undistorted by variations in clinical opinion on clinical significance.

The success of risk-adjusted monitoring on a national scale will depend on a linkage infrastructure that ensures data quality and minimises error due to linkage of imperfect or incomplete identifiers, while allowing for standardised, risk-adjusted analyses of infection rates. Our analyses quantify substantial reductions in BSI rates in two PICUS, but a national system is required to identify units where further improvements are needed and to determine which practice innovations have most impact.

Acknowledgments The authors would like to thank Tom Fleming (PICANet), Paul Lock and Joanna Bell (Great Ormond Street Hospital), Ollie Bagshaw and Adrian Bigland (Birmingham Children's Hospital) for helpful advice, contribution of data and

facilitation of data retrieval for this paper. We would like to thank all the staff in participating hospitals who have collected data for PICANet. We are grateful to the UK Paediatric Intensive Care Society for continued support and to the members of the PICANet Steering Group and Clinical Advisory Group who are listed on our website http://www.picanet.org.uk/participants.html. This work was supported by funding from the National Institute for Health Research Health Technology Assessment (NIHR HTA) programme (Project number 08/13/47). The views and opinions expressed therein are those of the authors and do not necessarily reflect those of the HTA programme, NIHR, NHS or the Department of Health. The authors state no conflicts of interest. PICANet is funded by the National Clinical Audit and Patient Outcomes Programme via Healthcare Quality Improvement Partnership (HQIP), Health Commission Wales Specialised Services, NHS Lothian/National Service Division NHS Scotland, the Royal Belfast Hospital for Sick Children, Our Lady's Children's Hospital, Crumlin, Children's University Hospital, Temple Street and The Harley Street Clinic, London.

Ethical approval Collection of personally identifiable data has been approved by the National Information Governance Board (Formerly the Patient Information Advisory Group) http://www.nigb.nhs.uk/s251/registerapp and ethical approval granted by the Trent Medical Research Ethics Committee, ref. 05/MRE04/17. Consent for the use of the data in this study was obtained by the PICANet unit leads.

References

1. Lakshmi KS, Jayashree M, Singhi S, Ray P (2007) Study of nosocomial primary bloodstream infections in a pediatric intensive care unit. J Trop Pediatr 53(2):87–92. doi: 10.1093/tropej/fml073
2. Abou Elella R, Najm H, Balkhy H, Bullard L, Kabbani M (2010) Impact of bloodstream infection on the outcome of children undergoing cardiac surgery. Pediatr Cardiol 31(4):483–489. doi: 10.1007/s00246-009-9624-x
3. Elward A, Hollenbeak C, Warren D, Fraser V (2005) Attributable cost of nosocomial primary bloodstream infection in pediatric intensive care unit patients. Pediatrics 115(4):868
4. Yogaraj J, Elward A, Fraser V (2002) Rate, risk factors, and outcomes of nosocomial primary bloodstream infection in pediatric intensive care unit patients. Pediatrics 110(3):481
5. Pronovost P, Goeschel C, Colantuoni E, Watson S, Lubomski L, Berenholtz S, Thompson D, Sinopoli D, Cosgrove S, Sexton J (2010) Sustaining reductions in catheter related bloodstream infections in Michigan intensive care units: observational study. BMJ 340:c309
6. Bhutta A, Gilliam C, Honeycutt M, Schexnayder S, Green J, Moss M, Anand K (2007) Reduction of bloodstream infections associated with catheters in paediatric intensive care unit: stepwise approach. BMJ 334(7589):362–365
7. Miller MR, Griswold M, Harris JM II, Yenokyan G, Huskins WC, Moss M, Rice TB, Ridling D, Campbell D, Margolis P, Muething S, Brilli RJ (2010) Decreasing PICU catheter-associated bloodstream infections: nACHRI's quality transformation efforts. Pediatrics 125(2):206–213. doi: 10.1542/peds.2009-1382
8. Department of Health (2005) Saving Lives: a delivery programme to reduce healthcare associated infections including MRSA. Department of Health, London
9. Pronovost PJ, Berenholtz SM, Needham DM (2008) Translating evidence into practice: a model for large scale knowledge translation. BMJ 337:a1714. doi:10.1136/bmj.a1714
10. Lilford R, Mohammed MA, Spiegelhalter D, Thomson R (2004) Use and misuse of process and outcome data in managing performance of acute medical care: avoiding institutional stigma. Lancet 363(9415):1147–1154
11. Davenport RJ, Dennis MS, Warlow CP (1996) Effect of correcting outcome data for case mix: an example from stroke medicine. BMJ 312(7045):1503–1505
12. García Álvarez L, Aylin P, Tian J, King C, Catchpole M, Hassall S, Whittaker-Axon K, Holmes A (2011) Data linkage between existing healthcare databases to support hospital epidemiology. J Hosp Infect 79(3):231–235
13. Lamagni T, Potz N, Powell D, Pebody R, Wilson J, Duckworth G (2011) Mortality in patients with meticillin-resistant Staphylococcus aureus bacteraemia, England 2004–2005. J Hosp Infect 77(1):16–20
14. Universities of Leeds and Leicester (2012) Paediatric Intensive Care Audit Network National Report 2009–2011. ISBN 9780853163121 Available: http://wwwpicanetorguk/Documents/General/Annual_Report_2012/Ninth_PICANet_Annual_Report_2009_2011_Summary_Reportpdf Accessed 19 September 2012
15. Slater A, Shann F, Pearson G (2003) PIM2: a revised version of the Paediatric Index of Mortality. Intens Care Med 29(2):278–285
16. Safdar N, Maki D (2004) The pathogenesis of catheter-related bloodstream infection with noncuffed short-term central venous catheters. Intens Care Med 30(1):62–67. doi: 10.1007/s00134-003-2045-z
17. O'Grady N, Alexander M, Dellinger E, Gerberding J, Heard S, Maki D, Masur H, McCormick R, Mermel L, Pearson M (2002) Guidelines for the prevention of intravascular catheter-related infections. Am Acad Pediatr Policy 110(5):e51–e74
18. Horan TC, Andrus M, Dudeck MA (2008) CDC/NHSN surveillance definition of health care—associated infection and criteria for specific types of infections in the acute care setting. Am J Infect Control 36(5):309–332
19. StataCorp (2009) Stata statistical software: release 11. StataCorp LP, College Station
20. Shann F, Pearson G, Slater A, Wilkinson K (1997) Paediatric index of mortality (PIM): a mortality prediction model for children in intensive care. Intens Care Med 23(2):201–207
21. Harron K, Ramachandra G, Mok Q, Gilbert R (2011) Consistency between guidelines and reported practice for reducing the risk of catheter-related infection in British paediatric intensive care units. Intens Care Med 37(10):1641–1647
22. Holman CDAJ, Preen DB, Baynham NJ, Finn JC, Semmens JB (2005) A multipurpose comorbidity scoring system performed better than the Charlson index. J Clin Epidemiol 58(10):1006–1014
23. Armitage J, van der Meulen J (2010) Identifying co-morbidity in surgical patients using administrative data with the Royal College of Surgeons Charlson Score. Brit J Surg 97(5):772–781

24. Quan H, Sundararajan V, Halfon P, Fong A, Burnand B, Luthi JC, Saunders LD, Beck CA, Feasby TE, Ghali WA (2005) Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care Nov 43(11):1130–1139
25. Preen DB, Holman CDAJ, Spilsbury K, Semmens JB, Brameld KJ (2006) Length of comorbidity lookback period affected regression model performance of administrative health data. J Clin Epidemiol 59(9):940–946
26. Centers for Disease Control and Prevention (2012) Central Line-Associated Bloodstream Infection (CLABSI) event: guidelines and procedures for monitoring CLABSI. National Healthcare Safety Network (NHSN) manual Atlanta, GA: NHSN (http://www.cdc.gov/nhsn/PDFs/pscManual/4PSC_CLABScurrent.pdf)
27. Laupland KB, Gregson DB, Vanderkooi OG, Ross T, Kellner JD (2009) The changing burden of pediatric bloodstream infections in Calgary, Canada, 2000–2006. Pediatr Infect Dis J 28(2):114
28. Kollef MH, Zilberberg MD, Shorr AF, Vo L, Schein J, Micek ST, Kim M (2011) Epidemiology, microbiology and outcomes of healthcare-associated and community-acquired bacteremia: a multicenter cohort study. J Infection 62(2):130–135