Title: Monitoring quality of care through linkage of administrative data: national trends in bloodstream infection in UK paediatric intensive care units 2003-2012

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Key Words: central venous catheters; child; infection control; intensive care; patient care bundles, data linkage; bloodstream infection; quality improvement; bacterial infections; laboratories, hospital; questionnaires; incidence

Funding Source: This work was supported by funding for the CATCH trial 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. Ruth Gilbert is supported by awards establishing the Farr Institute of Health Informatics Research London from the MRC, in partnership with nine other. PICANet is funded by the National Clinical Audit & Patient Outcomes Programme, administered by the Healthcare Quality Improvement Partnership (HQIP); Welsh Health Specialised Services Committee; NHS Lothian/National Service Division NHS Scotland; the Royal Belfast Hospital for Sick Children; National Office of Clinical Audit Ireland (NOCA) and HCA International.

ABSTRACT

Objectives: Interventions to reduce hospital-acquired bloodstream infection (BSI) have succeeded in reducing rates in US paediatric intensive care units (PICUs) but there is a lack of evidence for the impact of similar interventions in the UK. We assessed variation in BSI rates within and between PICUs over a 10-year period, during which time infection control strategies (care bundles) were implemented.

Design: Observational study linking laboratory data to national audit data of paediatric intensive care admissions (PICANet).

Setting: 20 PICUs in England and Wales, 2003-2012.

Patients: 102,999 children <16 years**.**

Interventions: Implementation of infection control strategies in PICU captured through a survey of clinicians.

Measurements and main results: Rates of BSI per 1000 bed-days were estimated from samples taken between 2 days after admission and up to 2 days following discharge from PICU. 2.0% of children experienced at least one BSI, corresponding to 5.11 (95% CI 4.90-5.31) per 1000 bed-days. There was a significant difference in trends pre-implementation of infection control strategies (annual decrease of 8.0%; 95% CI 6.3%-9.7%) versus post-implementation (annual decrease of 13.4%; 95% CI 10.3%-16.4%). By 24 months post-implementation, the rate of BSI fell 25.5% since the reported implementation date and was 15.1% lower than would have been expected if pre-implementation trends had continued.

Conclusions: Our population-based study of PICUs in England and Wales demonstrates a steady decline in BSI rates over time. In addition, there was a significant and incremental further decrease in rates associated with timing of implementation of infection control strategies. Assessment of BSI trends before as well as after implementation of infection control strategies can be facilitated using data linkage and is important to avoid over-estimating the impact of unit level interventions to improve infection control. Advances in collection and linkage of real-time data could further support quality improvement efforts.

Introduction

Bloodstream infection (BSI) is an important cause of adverse clinical outcome and cost to the UK National Health Service (NHS). Paediatric intensive care units (PICUs) have one of the highest reported rates of hospital-acquired BSI of any clinical specialty.(1-4) An estimated 70% of BSI in PICU is caused by central venous catheters (CVCs), an important focus for a number of quality improvement initiatives.(5-7) Interventions have succeeded in dramatically decreasing BSI rates in the US, with reported reductions of up to 66% in rates of catheter-related BSI 18 months post-implementation.(8, 9) Following a Comprehensive Spending Review in 2007 in the UK, the Department of Health invested £270 million a year to support infection prevention and control, including the updated *Saving Lives* CVC care bundle.(7, 10) However, there is a lack of evidence on the impact of these strategies, with monitoring mostly limited to process measures that were collated only locally.

The use of administrative healthcare data is being increasingly recognised as an efficient approach for monitoring quality of care.(11) In the UK, no single dataset captures both the clinical data on length of stay and microbiological BSI data required to derive risk-adjusted BSI rates.(12) However, linkage of data between the national laboratory surveillance database (LabBase2; coordinated by Public Health England) and clinical information from the Paediatric Intensive Care Audit Network (PICANet) provides the opportunity to estimate risk-adjusted BSI trends and efficiently monitor quality of care in PICUs in England and Wales.(13-15) We used these data to derive national trends in BSI in PICU over a ten-year period and to compare trends before and after the reported implementation of infection control strategies. Our study is the first to combine national data on BSI trends with reported changes in PICU practice.

Materials and methods

Although infection control strategies focussed on CVC-related BSI, we estimated rates of BSI from any source. This is justified by the importance of monitoring BSI whether a child has a CVC or not, and the hypothesis that infection control strategies may have broader implications (e.g. for hand hygiene or skin preparation).

To distinguish PICU from high dependency care, we restricted analyses to PICUs with more than 200 admissions per year on average (22/25 PICUs in England and Wales). We further excluded two PICUs due to a lack of reporting to LabBase2. The remaining 20 PICUs comprised 102,999/141,164=73% of total admissions to PICUs between 2003 and 2012.

Survey data

We surveyed all 22 PICUs by post or email between April and Sept 2012. A designated nurse and consultant were asked to complete a questionnaire relating to infection control practices designed to reduce CVC-related BSI in PICU and to give approximate dates for implementation of these strategies, which were based mainly on *Saving Lives* or *Matching Michigan* initiatives.(5, 7) Strategies relating to *Saving Lives* focussed on CVC insertion (guidelines for catheter type, insertion site, skin preparation, hand hygiene, aseptic technique, dressings etc.) or maintenance (guidelines for catheter site inspection, injection ports, catheter access, replacement of CVCs and administrative sets etc.).(7) Strategies relating to *Matching Michigan* (a two-year quality improvement project funded by the Department of Health; including 21 PICUs 2009-2010) aimed to improve guidance and training in insertion and maintenance of CVCs and to monitor BSI rates through a staff-reported daily census for each unit.(5)

PICU data

Data on all clinically relevant PICU admission characteristics for children aged <16 years from March 2003 to December 2012 were extracted from the PICANet database (t, Table 1).(13)

Microbiology data

All positive isolates from blood culture captured by the national laboratory surveillance system for children aged <16 years between 2003 and 2012 were extracted from LabBase2. (11, 15, 16) We have previously validated LabBase2 against reference data obtained directly from laboratories, and taking into account reporting gaps (e.g. through failure to upload), we estimated that LabBase2 ascertains 80-95% of clinically significant BSI in children.(17) Reporting gaps were due to system or staffing issues at the laboratory level and ascertainment was unrelated to individual patient or PICU-level factors such as the type of organism, time period or the number of reports. This means that valid comparison of trends between PICUs was still possible.(14)

Data linkage

A detailed description of the linkage between PICANet and LabBase2 has been published elsewhere.(14) Briefly, a combination of linkage methods was used to identify PICANet admission records that had a corresponding record of BSI in LabBase2, based on agreement between NHS number, Hospital number, first name, surname, date of birth, postcode, sex and location (laboratory and hospital). We evaluated the linkage against reference data and

demonstrated that linkage errors resulted in a small amount of bias (rates were underestimated by 0.5%).(14)

Case definition

We defined an episode of BSI as any positive blood culture with one or more organisms isolated from any blood sample taken on the same day. Repeated samples of the same organism within 14 days were treated as the same episode; two or more different organisms isolated on different days were treated as separate episodes. For children who already had BSI on admission, we excluded samples that were the same organism as that isolated before admission.

For this study, we were interested in BSI occurring during a PICU admission (PICU-acquired BSI). We therefore excluded samples taken on the day of admission to PICU or the day after admission. We included samples taken up to two days following discharge from PICU.

Analysis

The rate of BSI was defined as the number of BSI per 1000 bed-days. Multi-level Poisson regression was used to model the rate of BSI over time, allowing for clustering of admissions within PICUs (see supplementary Appendix 1). Backwards stepwise regression ($p<0.05$) was used to identify significant risk-factors based on admission characteristics in Table 1 (age in months and quarter-year of admission were treated as continuous variables within the model, all other variables were categorical). Model fit and non-linear relationships for age and time at risk were assessed using likelihood ratio tests, Akaike's Information Criterion, Bayesian Information Criterion, and diagnostic plots of residuals. Appropriateness of the

Poisson model was verified using a goodness-of-fit test based on the deviance statistic. Smoothed rates were plotted on the log-scale (with 0.5 added to observations where observed rate=0). Incidence-rate ratios were used to compare rates according to different risk-factors. Analysis was performed using Stata 12.(18)

To examine differences in trends in periods before and after implementation of infection control strategies, a variable representing time was created, centred on implementation according to the survey responses. Where dates were different for insertion and maintenance bundles, the earliest date was used. For units where a year but no month was provided, mid-year was used in analysis. Analysis was restricted to PICUs where at least one implementation date had been provided. An interaction term between time and use of strategy was fitted in the model to test for differences in trends pre- and post-implementation. The expected trend, had there been no implementation of infection control strategies, was produced from model predictions. This trend was extrapolated for 24 months post-implementation, to derive the expected rate had there been no intervention. The expected trend was then compared with the observed trend 24-months post-implementation.

For the most recent period (2011-2012), by which time infection control strategies had been implemented, a funnel plot was used to examine the variation among PICUs in risk-adjusted rates.(19) To account for different patient populations at different PICUs, risk-adjusted rates for each PICU were produced by dividing the PICU's unadjusted rate by its predicted rate, and multiplying this ratio by the average rate across all PICUs.(19) This plot indicated whether the rate in an individual PICU differed significantly from the national rate.

Results

Rates of BSI

Between March 2003 and December 2012, there were 102,999 admissions to the 20 study PICUs, corresponding to a total of 479,641 bed-days. For these admissions, there were 2452 episodes of BSI, and 2045 admissions (2.0%) experienced at least one BSI (Table 1). The overall rate of BSI was 5.11 (95% CI 4.90-5.31) per 1000 bed-days. Quarter-year of admission, age, vasoactive agent, renal support, primary diagnosis group on admission and ventilation status (invasive only, non-invasive only, both or neither) were independently significantly associated with BSI (Table 2).

Trends in BSI

Risk-adjusted rates of BSI (controlling for independent risk-factors for BSI in Table 2) decreased across all 20 PICUs by an annual average of 13.2% (95% CI 11.8-14.6%). Risk-adjusted rates fell from 8.96 (95% CI 7.72-10.20) per 1000 bed-days in 2003 to 2.87 (95% CI 2.40-3.35) in 2012. This corresponded to an absolute rate reduction of 68% over the ten year period. Rates were falling at a faster rate in admissions diagnosed with infection compared with other diagnoses and by the end of the study period, rates in children admitted with a primary diagnosis of infection were similar to those for children admitted for cardiovascular problems (Figure 1). Adjusted trends in BSI differed between PICUs (Figure 2).

Survey data

Fourteen PICUs provided survey responses on the implementation of infection control strategies (Table 3). For these PICUs, there was a significant difference in trends pre- and post-implementation for all admissions: adjusted rates were decreasing by 8.0% (95% CI 6.3-9.7%) per year pre-implementation and decreasing by 13.4% (95% CI 10.3-16.4) per year post-implementation. The observed rate of BSI fell 25.5% from 4.47 (95% CI 2.52-6.42) per 1000 bed-days at the time of implementation to 3.33 (95% CI 1.34-5.32) 24 months post-implementation (based on 12/14 PICUs with data at 24 months post-implementation, see Figure 3). Assuming pre-implementation trends had continued at the same rate, the expected rate for 24 months post-implementation was 3.92 (95% CI 1.76-6.08), corresponding to an absolute rate reduction of 15.1%.

Variation between PICUs

Data for the most recent years (2011-2012) was available for 18 PICUs. Figure 4 shows significant variation in the risk-adjusted rate of BSI between PICUs in this period (confidence intervals for PICUs with highest and lowest rates do not overlap). However, variation was not attributed to one particular outlying PICU. The funnel plot shows that the majority of PICUs fell within the expected range of the national rate (Figure 4).

Discussion

Our population-based study of PICUs in England and Wales quantifies a steady decline in BSI rates over time. Use of longitudinal administrative data allowed us to identify that rates were decreasing in all main clinical groups long before implementation of specific infection control strategies. However, we demonstrate that there was a significant and incremental further decrease in rates associated with the timing of implementation of infection control strategies, over and above background trends. We estimated that 24 months after implementation, BSI rates for all children in PICU had fallen by 26% and were 15% lower than they would have been had pre-implementation trends continued. Decreases in rates were not restricted to children with CVCs, and this may have been achieved through improvements in infection control more generally (such as hand hygiene).(7) Our study demonstrates that linkage of administrative data can be used for long-term continuous monitoring of a broad range of outcomes and is important for capturing trends before as well as after infection control initiatives to avoid wrongly attributed interventional effects.(5)

Like previous studies evaluating implementation of infection control strategies or care bundles, our study was an observational analysis with trends potentially affected by factors other than reported practice.(5) This is demonstrated by the 8% annual decline in BSI rates pre-implementation of infection control strategies in our study. The decrease in rates of BSI (26%) in 24 months following the introduction of infection control strategies was a smaller reduction than seen in other studies reporting the impact of interventions in US adult ICUs (reduction of up to 66%) and in two UK studies (reported reductions of 50-75%).(11, 20, 21) The small effect in our study may have been due in part to uncertainty around

implementation dates as recorded in clinician survey responses, which may have resulted in an underestimated impact due to recall bias. Strategies in place prior to the implementation dates used in our analysis may have contributed to the observed effect.(22) Alternatively, other studies may not have fully taken into account declining background trends for all patients. We were unable to directly compare results with other studies as we could not derive rates per CVC-days.

This study was only possible through the linkage of national data on PICU admissions and infection surveillance, which offered an efficient and cost-effective method for exploiting existing data with comprehensive coverage over an extended study period. Linkage between PICANet and LabBase2 provides a rich but imperfect dataset allowing enhanced monitoring of BSI in PICU. Our study was limited in that the surveillance data did not provide a validated diagnosis of BSI in PICU and may have included BSI that should be considered as contaminants. We were also unable to investigate changes in sampling frequency over time, or to directly identify children who required a CVC. Data quality in administrative data can be an issue but, as in this case, may not necessarily be conditioned on the exposure or outcomes of interest. While monitoring schemes for specific implementation studies can pre-specify the data to be collected, they are costly, do not capture data pre-intervention, and can be dependent on clinician judgement of outcomes.(23) In contrast, administrative data provides the opportunity to analyse routinely-recorded data for entire units and to take into account background trends before and during implementation of interventions.

Conclusion

Linkage of national administrative data sources provides an opportunity to monitor quality of care through enhanced surveillance of BSI trends in PICU. In the UK PICUs, rates of BSI were already falling before the implementation of infection control strategies, but these interventions were associated with a significant additional reduction in BSI. Standardised recording of unit-level interventions could help to increase understanding of variations in practice, and to identify interventions that lead to improvements in outcomes. The combination of improved characterisation of unit practices and monitoring of BSI using linked administrative data would allow PICUs most likely to benefit from improved practices to learn from others. Monitoring quality of care by measuring variation in BSI outcomes in PICU could then help to sustain improvements in practice.(24, 25)

ACKNOWLEDGEMENTS

The authors would like to thank Tom Fleming, Phil McShane and Lee Norman (PICANet) for facilitation of data retrieval for this paper. 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 the PICANet website http://www.picanet.org.uk/About/. We would like to thank all the staff in participating hospitals who have collected data for PICANet or responded to survey questionnaires (Barts and the London NHS Trust, The Royal London Hospital; Birmingham Children's Hospital NHS Trust, Birmingham Children's Hospital; Brighton & Sussex University Hospitals NHS Trust, The Royal Alexandra Children's Hospital; Cambridge University Hospitals NHS Foundation Trust, Addenbrooke's Hospital; Cardiff & Vale NHS Trust, University Hospital of Wales; Central Manchester University Hospitals NHS Foundation Trust, Royal Manchester Children's Hospital; Great Ormond Street Hospital for Children NHS Trust, Great Ormond Street Hospital for Children; Guy's & St. Thomas' NHS Foundation Trust, Evelina London Children's Hospital; Hull & East Yorkshire Hospitals NHS Trust, Hull Royal Infirmary; Imperial College Healthcare NHS Trust , St. Mary's Hospital; King's College Hospital NHS Trust, King's College Hospital; Leeds Teaching Hospitals NHS Trust, Leeds General Infirmary; Liverpool Alder Hey Children's NHS Foundation Trust, Liverpool Alder Hey Children's Hospital; Newcastle Upon Tyne Hospitals NHS Foundation Trust, Great North Children's Hospital& Newcastle Freeman Hospital; Nottingham University Hospitals NHS Trust, Nottingham Childrens Hospital, Queen's Medical Centre; Oxford University Hospitals NHS Trust, The John Radcliffe Hospital; Royal Brompton & Harefield NHS Foundation Trust, Royal Brompton Hospital; Sheffield Children's NHS Foundation Trust, Sheffield Children's Hospital; South Tees Hospitals NHS Foundation Trust; St. George's Healthcare NHS Trust, St. George's Hospital; The James Cook University Hospital; University Hospital of North Staffordshire NHS Trust, University Hospital of North Staffordshire; University Hospital Southampton NHS Foundation Trust, Southampton Children's Hospital; University Hospitals Bristol NHS Foundation Trust, Bristol Royal Hospital for Children; University Hospitals of Leicester NHS Trust, Leicester Royal Infirmary & Leicester Glenfield Hospital.

ETHICS

For PICANet, 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. PICANet also has specific permission from the National Research Ethics Service for linkage with the PHE laboratory data on bloodstream infections using personal identifiers and to share PICANet data with PHE. An exemption under Section 251 of the NHS Act 2006 (previously Section 60 of the

Health and Social Care Act 2001) allows PHE to receive patient-identifiable data from other organisations without patient consent in order to monitor infectious disease. Specific permission for the PICANet-PHE linkage has been granted by National Information Governance Board for Health and Social Care.

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Table 1: Characteristics of admissions to paediatric intensive care units (PICUs) in England and Wales 2003-2012. BSI = bloodstream infection; HDU = high dependency unit; A&E = accident and emergency; NICU = neonatal intensive care unit; PIM2 = paediatric index of mortality score (version 2).

		Admissions with no BSI (n=100,954)		Admissions with BSI (n=2,045)	
		n	%	n	%
Sex	Male	57,205	56.7	1,186	58.0
	Female	43,686	43.3	859	42.0
	Unknown	63	0.1	0	0.0
Age	<1 month	15,395	15.2	443	21.7
	1 - <12 months	31,075	30.8	828	40.5
	1 – 4 years	26,745	26.5	455	22.3
	5 – 10 years	14,135	14.0	183	9.0
	11 – 15 years	13,604	13.5	136	6.7
	Unknown	1	0.0	0	0.0
Length of stay in hours	1-<4	3,336	3.3	5	0.2
	4-<12	7,307	7.2	15	0.7
	12-<24	19,751	19.6	52	2.6
	24-<48	21,722	21.5	80	3.9
	48+	48,838	48.4	1,893	92.6
Vasoactive agent	Yes	29,254	29.0	1,192	58.3
Renal support	Yes	3,184	3.2	336	16.4
Retrieval	Yes	34,525	34.2	868	42.4
Retrieval team	Non-specialist team	1,889	5.5	29	3.3
	Other specialist team	12,126	35.1	309	35.6
	Own team	20,061	58.1	515	59.3
	Unknown	449	1.3	15	1.7
Care area of admission	A&E	17,326	17.2	238	11.6
	HDU (step-up/step-down unit)	4,082	4.0	104	5.1
	ICU / PICU / NICU	10,983	10.9	389	19.0
	Other intermediate care area	1,748	1.7	52	2.5
	Recovery only	629	0.6	12	0.6
	Theatre and recovery	38,353	38.0	603	29.5
	X-ray / endoscopy / CT scanner	746	0.7	10	0.5
	Ward	23,135	22.9	571	27.9
	Unknown	3,952	3.9	66	3.2
Ventilation status	Neither	31,497	31.2	253	12.4
	Non-invasive only	4,902	4.9	32	1.6
	Invasive only	52,162	51.7	1,118	54.7
	Both	11,022	10.9	597	29.2
	Unknown	1,371	1.4	45	2.2
Admission type	Planned	39,216	38.8	683	33.4
	Unplanned	61,511	60.9	1,357	66.4
	Unknown	227	0.2	5	0.2
Admission source	Same hospital	62,252	61.7	1,104	54.0
	Other hospital	37,515	37.2	936	45.8
	Unknown	1,187	1.2	5	0.2
PIM2	<1%	29,518	29.2	237	11.6
	1-5%	44,432	44.0	810	39.6
	5-15%	19,663	19.5	626	30.6
	15-30%	4,250	4.2	229	11.2
	30%+	3,091	3.1	143	7.0
Primary diagnosis group on admission	Cardiology	28,313	28.0	733	35.8
	Respiratory	27,569	27.3	451	22.0
	Infection	5,482	5.4	265	12.9

	Other	39,590	39.2	596	29.1
Unit type	General	38,727	38.4	607	29.7
	Mixed	58,729	58.2	1,330	65.0
	Cardiac	3,498	3.5	108	5.3
Unit size	0-650	32,564	32.3	463	22.6
	650-1000	46,291	45.9	1,017	49.7
	>1000	22,099	21.9	565	27.6

Table 2: Independent risk-factors for bloodstream infection based on multi-level Poisson model. Quarter-year of admission is a continuous variable for 3-monthly periods from January-March 2003 to October-December 2012.*p-value<0.05; ** p-value<0.001

		Incidence-rate ratio	95% confidence interval
Age (in months)		0.996**	0.996-0.997
Vasoactive agent		1.61**	1.45-1.79
Renal support		1.46**	1.31-1.63
Quarter-year of admission		0.97**	0.96-0.97
Ventilation status	Neither	1.00	
	Non-invasive only	0.67*	0.46-0.96
	Invasive only	1.03	0.88-1.21
	Both	1.13	0.96-1.34
Primary diagnosis group on admission	Other	1.00	
	Cardiology	0.90	0.80-1.01
	Respiratory	0.58**	0.52-0.66
	Infection	1.72**	1.49-1.98

Table 3: Survey responses to questions relating to infection control strategies for central venous catheter (CVC) care, from the 20 paediatric intensive care units (PICUs) analysed.

	Insertion		Maintenance	
PICU	Do you use a care bundle for Insertion of CVCs?	If yes, please give an approximate month and year for when the care bundle was first implemented	Do you use a care bundle for the Ongoing Care of CVCs?	If yes, please give an approximate month and year for when the care bundle was first implemented
1	Yes	2011	Don't know	
2	Yes	January 2008	Yes	January 2008
3	Yes	August 2007	Yes	August 2004
4	Yes	2010	Yes	2007
5	Yes	Currently being revised	Yes	
6	Yes	January 2009	No	
7	Yes	November 2009	Yes	
8	No		Yes	June 2007
9	Yes	March 2011	Yes	March 2011
10	Yes	May 2010	Yes	May 2010
11	Did not return survey			
12	Did not return survey			
13	Yes	2010	Yes	2010
14	Yes	September 2009	Yes	September 2009
15	Yes	January 2010	Yes	July 2010
16	Yes	January 2010	Yes	January 2010
17	No		Yes	
18	Did not return survey			
19	Yes	May 2009	No	
20	No		No	

Figure 1: Trends in rates of bloodstream infection (BSI) per 1000 bed-days by primary diagnosis group at admission. Averaging across all admission groups, rates decreased by 13% per year. Symbols=observed rates for each diagnosis group; lines=smoothed adjusted rates.

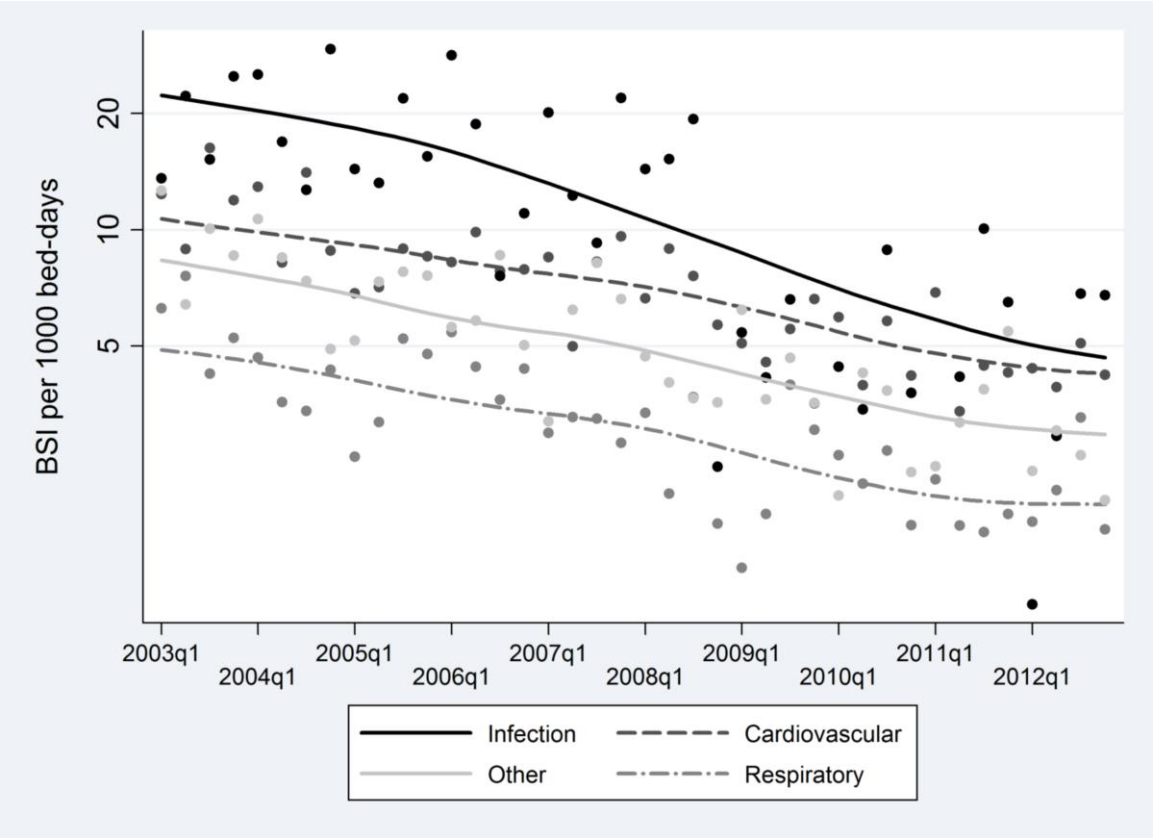

Figure 2: Varying trends in rates of bloodstream infection (BSI) per 1000 bed-days by PICU of admission. Vertical lines show implementation dates of infection control strategies for CVC insertion and maintenance according to survey responses. Symbols=model rates; lines=smoothed model rates.

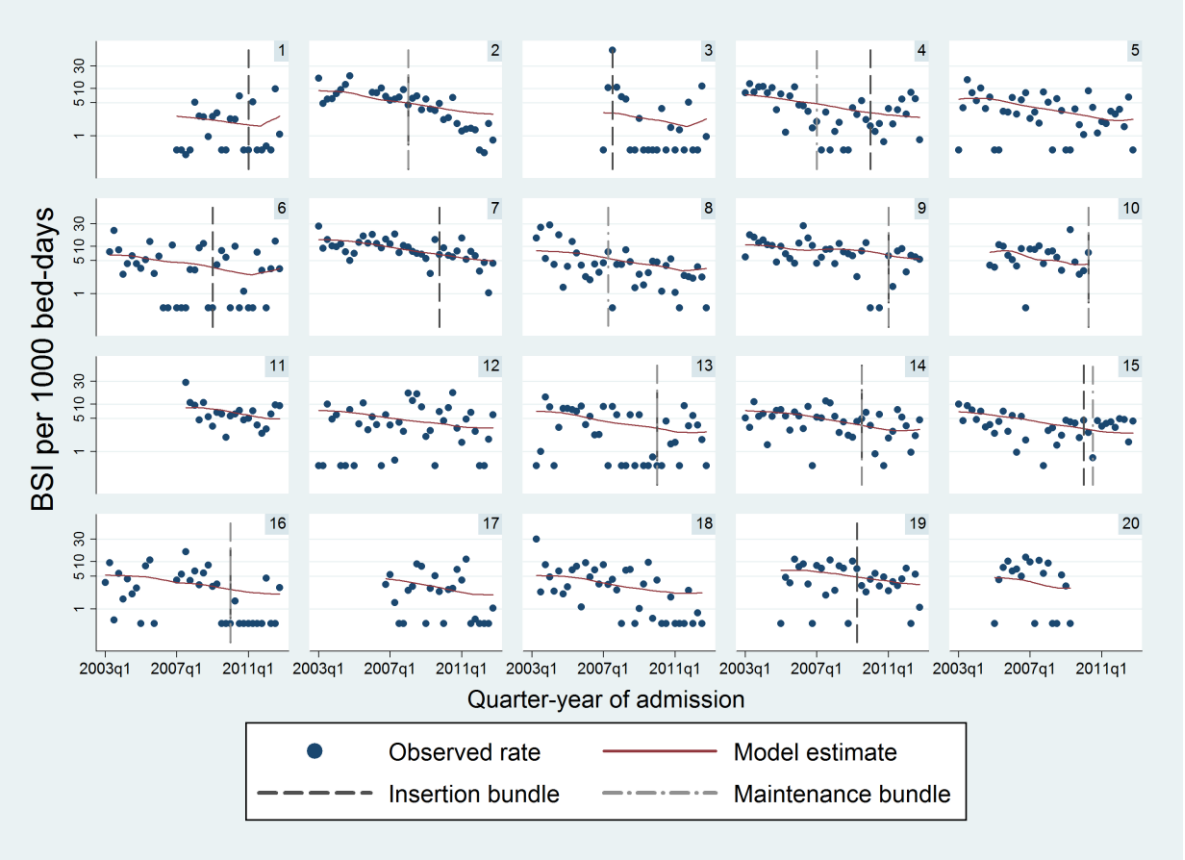

Figure 3: Trends in rates of bloodstream infection (BSI) per 1000 bed-days for pre- and post-implementation of infection control strategies in 12 PICUs. Data are centred at date of implementation (0 months since bundle implementation). By 24-months post-implementation, rates were 15% lower than would have been expected if pre-implementation rates had continued with the same trend. Symbols = observed rates by 30-days; solid lines = smoothed adjusted rates; dashed line = predicted rate if trend in pre-implementation period had continued.

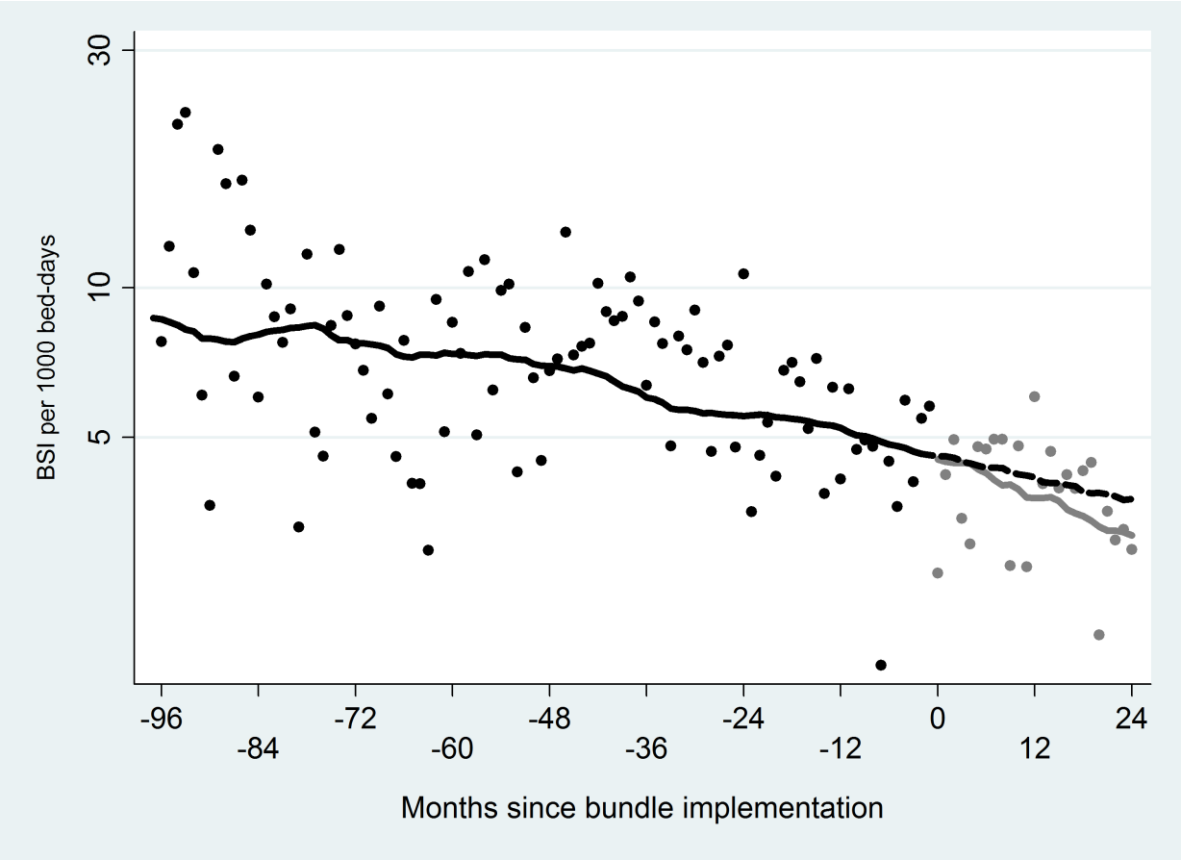

Figure 4: Caterpillar and funnel plot showing risk-adjusted rates of BSI in 18 PICUs in England and Wales 2011-2012. PICUs 10 and 20 were excluded due to a lack of data in these years. Confidence intervals for PICUs with highest and lowest rates in the caterpillar plot do not overlap, showing shows significant variation in risk-adjusted rates of BSI between PICUs. The majority of PICUs fall within the 95% funnel plot limits, showing that most PICUs were had rates within an expected distance from the national average.