Health-care-associated bloodstream and urinary tract infections in a network of hospitals in India: a multicentre, hospital-based, prospective surveillance study

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Summary

Background Health-care-associated infections (HAIs) cause significant morbidity and mortality globally, including in low-income and middle-income countries (LMICs). Networks of hospitals implementing standardised HAI surveillance can provide valuable data on HAI burden, and identify and monitor HAI prevention gaps. Hospitals in many LMICs use HAI case definitions developed for higher-resourced settings, which require human resources and laboratory and imaging tests that are often not available.

Methods A network of 26 tertiary-level hospitals in India was created to implement HAI surveillance and prevention activities. Existing HAI case definitions were modified to facilitate standardised, resource-appropriate surveillance across hospitals. Hospitals identified health-care-associated bloodstream infections and urinary tract infections (UTIs) and reported clinical and microbiological data to the network for analysis.

Findings 26 network hospitals reported 2622 health-care-associated bloodstream infections and 737 health-care-associated UTIs from 89 intensive care units (ICUs) between May 1, 2017, and Oct 31, 2018. Central line-associated bloodstream infection rates were highest in neonatal ICUs (>20 per 1000 central line days). Catheter-associated UTI rates were highest in paediatric medical ICUs (4·5 per 1000 urinary catheter days). *Klebsiella* spp (24·8%) were the most frequent organism in bloodstream infections and *Candida* spp (29·4%) in UTIs. Carbapenem resistance was common in Gram-negative infections, occurring in 72% of bloodstream infections and 76% of UTIs caused by *Klebsiella* spp, 77% of bloodstream infections and 76% of UTIs caused by *Acinetobacter* spp, and 64% of bloodstream infections and 72% of UTIs caused by *Pseudomonas* spp.

Interpretation The first standardised HAI surveillance network in India has succeeded in implementing locally adapted and context-appropriate protocols consistently across hospitals and has been able to identify a large number of HAIs. Network data show high HAI and antimicrobial resistance rates in tertiary hospitals, showing the importance of implementing multimodal HAI prevention and antimicrobial resistance containment strategies.

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Introduction

Health-care-associated infections (HAIs) are a serious threat to patient safety, resulting in substantial morbidity and mortality across a wide variety of health-care settings. The burden of HAIs is higher in low-income and middle-income countries (LMICs) than in high-income countries.[1,2] WHO has included HAI surveillance in its core components of infection prevention and control programmes at the health-care facility and national levels.[3] HAI surveillance data can provide information on HAI burden, assess HAI trends over time, identify areas requiring improvement in HAI prevention activities, and monitor infection prevention and control interventions to prevent HAIs. Establishing and sustaining HAI surveillance requires commitment from health-care facility leadership and the investment of resources, which is often challenging in LMICs.[4]

A network approach to HAI surveillance that uses standardised case definitions and surveillance methodology across reporting facilities can provide high quality data but is difficult to implement.[5] Case definitions used in HAI surveillance can be complex and are often not applied consistently across hospitals.[6–8] Any variations in the implementation of surveillance methodology or

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Research in context

Evidence before this study

Health-care-associated infections (HAIs) cause significant morbidity and mortality in low-income and middle-income countries but creating surveillance systems to monitor these infections can be resource intensive. We searched PubMed to identify studies that describe device-associated HAIs in India that were published since Jan 1, 2015, using search terms "India" AND ("healthcare-associated infection" OR "central line-associated bloodstream infection" OR "catheter-associated urinary tract infection" OR "ventilator-associated pneumonia"). We found many single-hospital studies that describe HAIs in one or multiple intensive care units and several reports from international HAI surveillance consortia that include Indian hospitals in their networks that use surveillance methodology and protocols from the USA.

Added value of this study

We did not identify any networks of Indian hospitals that conduct HAI surveillance using a standardised methodology that has been adapted to account for resource constraints that are commonly found in Indian health facilities. We have created a network of large Indian public and private hospitals that conduct HAI surveillance and prevention activities using protocols inspired by gold standard methods in the USA and Europe with modifications to reflect limitations in human resources and diagnostic testing often found in the Indian setting. By using methods that can be consistently implemented across surveillance sites and investing in efforts to maximise data quality, our network has produced pooled rates that show that health-care-associated bloodstream infections and urinary tract infections are serious problems in Indian intensive care units.

Implications of all the available evidence

Health-care-associated bloodstream infections and urinary tract infections are common in India and the pathogens that cause them often exhibit high levels of antimicrobial resistance. Indian hospitals should invest in infection prevention and control activities that can be implemented to prevent HAIs, particularly in patients in intensive care units with indwelling medical devices.

definitions across reporting facilities can lead to inaccurate estimates of burden and limit the ability to assess changes in incidence rates at a network level.

In LMICs, insufficient human and financial resources dedicated to infection prevention and control and reduced capacity for diagnostic testing, including clinical microbiology services, serve as additional challenges for HAI surveillance systems that use case definitions and methodologies from more developed settings.[9] To maximise the quality of HAI surveillance data in LMICs, surveillance systems should be integrated into existing clinical and administrative processes and develop case definitions that accurately reflect the availability of laboratory and other diagnostic tests at participating health-care facilities.[10,11]

Some health-care facilities in India have HAI surveillance systems that use case definitions from existing surveillance systems, such as the National Healthcare Safety Network (NHSN) by the US Centers for Disease Control and Prevention (CDC), despite limitations in human resources and diagnostic capacity that often exist.[12,13] Several tertiary care hospitals in India participate in international HAI surveillance collaborations.[14–17] However, no national coordination body for HAI surveillance exists in India, and no national, standardised HAI surveillance system has been implemented.

The Indian Council of Medical Research (ICMR), in collaboration with the All India Institute of Medical Sciences and the India National Centre for Disease Control (NCDC), has created the first network of tertiary care hospitals in India using standardised HAI suveillance methods that more accurately reflect resources available in Indian hospitals as part of the Indian Ministry of Health and Family Welfare's National Action Plan on Antimicrobial Resistance.[18] Here, we describe the results from the early implementation of this surveillance network.

Methods

Study design

In this multicentre, hospital-based, prospective surveillance study, a subset of 26 tertiary-level hospitals in India with active, staffed teams for infection prevention and control, and quality-assured microbiology laboratories participating in the ICMR's Antimicrobial Resistance Surveillance and Research Network and the NCDC's National Antimicrobial Resistance Surveillance Network, were invited to join the HAI surveillance network coordinated by the All India Institute of Medical Sciences, New Delhi.[19,20] Five hospitals with extensive experience implementing infection prevention and control programmes piloted HAI surveillance activities in late 2016. Subsequently, new hospitals joined the surveillance network to improve geographical and ownership diversity. All hospitals had leadership commitment to improve infection prevention and control at their facilities, but programme capacity varied across hospitals. Additional details on the participating hospitals are available in appendix 2 (pp 3–4).

A technical working group was established to develop surveillance protocols and an implementation plan for the HAI surveillance network. The technical working group developed case definitions for health-care-associated bloodstream infections, including central-line-associated bloodstream infections (CLABSIs), and urinary tract infections (UTIs), including catheter-associated UTIs

(CAUTIs), on the basis of case definitions used by the NHSN and the European Centre for Disease Prevention and Control (ECDC) Healthcare-associated Infections Surveillance Network.[21,22]

Modifications to NHSN and ECDC definitions were made to facilitate standardised implementation of surveillance across sites and address anticipated challenges. For example, reportable HAIs were defined as those occurring 2 or more days after admission to an intensive care unit (ICU) since tracking patient movement between units in large hospitals can be difficult due to scarce human resources for infection prevention and control teams and inadequate documentation in medical records. To facilitate identification of UTIs, only culture-confirmed infections (eg, those with urine culture colony counts greater than 10^5 CFU/mL), including those caused by *Candida* spp, were included in surveillance.

To address the inconsistent availability and use of laboratory and imaging tests required to determine whether a bloodstream infection was secondary to an infection at another body site with NHSN protocols, a modified bloodstream infection classification system that uses only culture results was developed. Secondary bloodstream infections were defined as those in which all organisms in the patient's blood culture were identified in a culture from another body site from 7 days before the infection date to 14 days after the infection date. All other bloodstream infections were defined as primary.

Case definitions used in the HAI surveillance network are summarised in the panel. Key differences between the case definitions used in the HAI surveillance network and those used by NHSN and ECDC are summarised in appendix 2 (p 5). Full surveillance protocols are available online.[23]

***Panel*: Surveillance case definitions**

Health-care-associated bloodstream infection (all points below should be met)

- Bloodstream infection occurs more than 2 days after admission to surveillance ICU
- No bloodstream infection reported for the patient in the past 14 days
- Patient has positive blood culture with at least one recognised pathogen, or at least two positive blood cultures with the same common commensal and at least one sign or symptom of a bloodstream infection

Classifications of health-care-associated bloodstream infections

- Secondary bloodstream infection: a bloodstream infection in which all organisms identified in blood culture are also identified in cultures from any other body site in the 7 days before or the 14 days after the infection date
- Primary bloodstream infection: a bloodstream infection in which at least one organism identified in blood culture is not identified in cultures from any other body site in the 7 days before or the 14 days after the infection date
- Central line-associated bloodstream infection: a primary bloodstream infection in which a central line was in place for more than 2 days on the infection date, or where a central line had been in place for more than 2 days but removed on the day of or the day before the infection date
- Primary bloodstream infection not associated with a central line: a primary bloodstream infection in which a central line was not in place on the day of or the day before the infection date

Health-care-associated urinary tract infection (all points below should be met)

- UTI occurs more than 2 days after admission to surveillance ICU
- No UTI reported for the patient in the past 14 days
- Patient has positive urine culture with no more than two species of organism, with least one organism growing at ≥10^5 CFU/mL
- Patient has at least one sign or symptom of a UTI

Classifications of health-care-associated urinary tract infections

- Catheter-associated UTI: a UTI in which an indwelling urinary catheter was in place for more than 2 days on the infection date, or an indwelling urinary catheter had been in place for more than 2 days but removed on the day of or the day before the infection date
- UTI not associated with a catheter: a UTI in which an indwelling urinary catheter was not in place on the day of or the day before the infection date

UTI=urinary tract infections. ICU=intensive care unit.

Participants

Each participating hospital enrolled at least one ICU treating adult medical patients, one ICU treating adult surgical patients, and one paediatric ICU in both bloodstream infection and UTI surveillance. Hospitals mapped each of their individual ICUs participating in surveillance to standard ICU types provided by network coordinators. Hospitals could enrol neonatal ICUs (NICUs) in bloodstream infection surveillance, but UTI surveillance was not done in NICUs because of the low frequency of urine culture and urinary catheter utilisation. Surveillance teams from each hospital participated in a 2-day training workshop led by the network coordination team following enrolment, with refresher trainings provided during meetings of network investigators held at least twice per year and as part of the network coordination team's site visits to hospitals.

The hospital surveillance teams prospectively identified bloodstream infections and UTIs in their enrolled ICUs. A standard case report form collecting demographic and clinical data, information on up to three pathogens causing the infection and their routine antimicrobial susceptibility testing (AST) results, and patient outcomes was completed for all bloodstream infections and UTIs meeting the case definition. Bloodstream infections and UTIs with multiple pathogens reported were counted as a single infection. Daily counts of patient days, central line days (including umbilical catheter days in NICUs), and urinary catheter days were collected from each ICU. Patient day and central-line day counts were stratified by five birthweight categories in NICUs.

Procedures

A web-based surveillance data reporting, aggregation, and analysis platform was developed. Hospitals entered infections meeting the bloodstream infection and UTI case definitions and denominator data into the online

	Hospitals (n=26)
Ownership	
Public	17 (65%)
Private or trust owned	8 (31)
Military	1 (4%)
Total number of beds	
≤500	3 (12%)
501–1000	9 (35%)
1001–1500	7 (27%)
≥1501	7 (27%)
Hospital type	
Multispecialty	24 (92%)
Trauma	1 (4%)
Oncology	1 (4%)
Type of medical education programme	
Undergraduate	20 (77%)
Graduate	6 (23%)

Data are n (%).

Table 1: **Characteristics of hospitals reporting surveillance data for health-care-associated infections**

	ICUs (n=89)
Medical	20 (22%)
Paediatric medical	14 (16%)
Neonatal	11 (12%)
Surgical	11 (12%)
Medical and surgical	9 (10%)
Cardiothoracic surgical	4 (4%)
Gastrointestinal	3 (3%)
Trauma surgical	3 (3%)
High dependency unit	3 (3%)
Neurosurgical	2 (2%)
Paediatric medical and surgical	2 (2%)
Respiratory	2 (2%)
Burn	1 (1%)
Cardiac	1 (1%)
Neurological	1 (1%)
Oncological medical	1 (1%)
Oncological surgical	1 (1%)

Data are n (%). ICU=intensive care unit.

Table 2: **Classification of ICUs reporting surveillance data for health-care-associated infections**

platform at least monthly after replacing personal identifiers with a unique identification number. The platform automatically classified bloodstream infections and UTIs into subcategories using data in the case report form. Bloodstream infections were classified as CLABSI, primary bloodstream infection not associated with a central line, or secondary bloodstream infection. UTIs were classified as CAUTI or UTI not associated with a urinary catheter. Hospitals could visualise and analyse their own data; the network coordination team was the only group with access to all hospitals' data with personal identifiers removed.

Hospitals reported pathogen and AST results in each bloodstream infection and UTI case report form with data reported from microbiology laboratories through their existing bacterial and fungal isolation, identification, and sensitivity testing processes (eg, use of automated systems or conventional manual microbiological techniques) using Clinical and Laboratory Standards Institute guidelines and breakpoints. Six sites did broth microdilution for colistin sensitivity testing; other sites tested for colistin sensitivity with disc diffusion or automated methods. Pathogens reported on bloodstream infection and UTI case report forms were aggregated across all reporting ICUs and ordered by their frequency. AST results reported in case report forms were aggregated by pathogen across all reporting ICUs. A series of priority antimicrobial resistance phenotypes was identified and the proportion of organisms showing the resistance pattern was calculated if at least 30 isolates were tested for the antibiotics of interest.

The network coordination team reviewed all data submitted by hospitals on a monthly basis to identify and address deficiencies. To assess the performance of individual hospitals and to ensure consistency of surveillance across sites, the network coordination team visited each hospital at least once, ideally shortly after starting surveillance activities. During these visits, structured tools reviewing the implementation of network protocols were used to identify gaps and deliver feedback to hospital surveillance teams.

Statistical analysis

Pooled overall bloodstream infection and UTI rates, CLABSI and CAUTI rates, and device utilisation ratios were calculated for each standard ICU type with at least five individual ICUs reporting at least one month of data. Standard ICU types were not combined for rate calculations. Bloodstream infection and CLABSI rates and device utilisation ratios were stratified by birthweight category in NICUs.

Overall health-care-associated bloodstream infection and UTI rates were expressed as infections per 1000 patient days and CLABSI and CAUTI rates as device-associated infections per 1000 device days. Device utilisation ratios were calculated by dividing the number of device days by the number of patient days. All analyses were done in Stata version 12.

Role of the funding source

Some authors involved in the conceptualisation and implementation of the study, the support of data collection and analysis, and manuscript development are employed by the US CDC. CDC and non-CDC authors were not precluded from accessing aggregated, analysed data in the study, agreed to proceed with manuscript development, and accepted the responsibility to submit it for publication.

	Adult ICUs	Paediatric ICUs	Neonatal ICUs	All ICUs combined
ICUs	62/89 (69·7%)	16/89 (18·0%)	11/89 (12·4%)	..
Bloodstream infections	1859/2622 (70·9%)	247/2622 (9·4%)	516/2622 (19·7%)	..
CLABSI	1023/1859 (55·0%)	116/247 (47·0%)	58/516 (11·2%)	1197/2622 (45·7%)
Primary bloodstream infections not associated with a central line	387/1859 (20·8%)	102/247 (41·3%)	451/516 (87·4%)	940/2622 (35·9%)
Secondary bloodstream infections	449/1859 (24·2%)	29/247 (11·7%)	7/516 (1·4%)	485/2622 (18·5%)
UTIs	656/737 (89·0%)	81/737 (11·0%)	..	..
CAUTI	637/656 (97·1%)	67/81 (82·7%)	..	704/737 (95·5%)
UTIs not associated with a urinary catheter	19/656 (2·9%)	14/81 (17·3%)	..	33/737 (4·5%)
Central line days	118 866	12 216	2341	133 423
Urinary catheter days	225 045	14 699	..	239 744
Patient days	291 501	47 266	53 883	392 650

Data are n/N (%) or n. UTI=urinary tract infection. ICU=intensive care unit. CLABSI=central-line-associated bloodstream infection. CAUTI=catheter-associated UTI.

Table 3: **Bloodstream infections and UTIs reported by ICU type**

Results

26 hospitals in 20 states and union territories reported bloodstream infection and UTI surveillance data for at least one month to the network between May 1, 2017, and Oct 31, 2018. Most hospitals (65%) were in the public sector, with private and military hospitals also reporting data. The majority (54%) of reporting hospitals contained more than 1000 beds. Hospital demographic data are summarised in table 1.

Data were reported from 89 individual ICUs mapped to 17 standard ICU types, with medical (22%) and paediatric medical (16%) ICUs being the most common. Five ICU types (medical, paediatric medical, neonatal, surgical, and medical and surgical) met the reporting threshold of five ICUs for calculating pooled rates and device utilisation ratios. All ICU types that data were reported from are listed in table 2.

All health-care-associated bloodstream infections and UTIs identified during the reporting period are summarised in table 3. Hospitals reported 2622 cases of bloodstream infections, with 1859 (70·9%) from adult ICUs, 247 (9·4%) from paediatric ICUs, and 516 (19·7%) from NICUs. Among all bloodstream infections reported, 45·7% were classified as CLABSIs, 35·9% were classified as primary bloodstream infections not associated with a central line, and 18·5% were classified as secondary bloodstream infections. Among the 485 secondary bloodstream infections, 327 (67·4%) reported a matching culture with a respiratory source. Of the 2622 bloodstream infections, 39 (1·5%), including 25 (2·1%) of 1197 CLABSIs, met the case definition using common commensal criteria. All other bloodstream infections met the case definition using recognised pathogen criteria. Hospitals reported 737 UTI cases from adult ICUs (n=656) and paediatric ICUs (n=81). 704 (95·5%) of 737 UTIs were classified as CAUTI and 33 (4·5%) were classified as UTIs not associated with a urinary catheter.

Pooled HAI rates and central line utilisation ratios for the five ICU types that met the five-ICU threshold are included in table 4. In adult and paediatric ICU types, the highest pooled rates of bloodstream infections (7·3 per 1000 patient days), CLABSI (12·1 per 1000 central line days), and UTIs (2·8 per 1000 patient days) were reported from surgical ICUs. Surgical ICUs also reported the highest device utilisation (central line utilisation ratio 0·51; urinary catheter utilisation ratio 0·81). Paediatric medical ICUs reported the lowest pooled bloodstream infections (5·3 per 1000 patient days) and UTIs (1·7 per 1000 patient days), and device utilisation (central line utilisation ratio 0·25; urinary catheter utilisation ratio 0·32), but saw relatively high device-associated infection rates. Neonatal ICUs reported high pooled bloodstream infection and CLABSI rates in all birthweight categories, with the highest rate of bloodstream infections (21·0 per 1000 patient days) and CLABSIs (33·7 per 1000 central line days) in the lowest birthweight category (≤750 g). All five birthweight categories reported pooled CLABSI rates over 20 per 1000 central line days. Additional information on bloodstream infection and UTI rates can be found in appendix 2 (pp 10–12).

Hospitals identified 2828 pathogens in the 2622 bloodstream infections reported, and 809 pathogens in the 737 UTIs reported (table 5). *Klebsiella* spp were the most frequently identified pathogens among bloodstream infections (701 [24·8%] of 2828 pathogens), followed by *Acinetobacter* spp (601 [21·3%]) and *Candida* spp (333 [11·8%]). Among UTIs, *Candida* spp were the most frequently identified pathogens (238 [29·4%] of 809), followed by *Enterococcus* spp (147 [18·2%]) and *Escherichia* spp (142 [17·6%]). *Candida auris*, an emerging multidrug-resistant threat, was reported as a pathogen in 33 (1·3%) of 2622 bloodstream infections and 11 (1·5%) of 737 UTIs. Additional information on pathogens reported can be found in appendix 2 (pp 6–9).

	ICUs	Months reported	All BSIs	All UTIs	Patient days	Pooled BSI rate per 1000 patient days*	Pooled UTI rate per 1000 patient days†	CLABSI	CAUTI	Central line days	Urinary catheter days	Pooled CLABSI rate per 1000 central line days‡	Pooled CAUTI rate per 1000 urinary catheter days§	CLUR¶	UCUR‖
Medical	20	244	471	200	83 926	5·6	2·4	217	195	25 167	67 894	8·6	2·9	0·30	0·81
Medical and surgical	9	155	547	152	85 028	6·4	1·8	246	149	29 695	60 871	8·3	2·5	0·35	0·72
Surgical	11	132	224	85	30 580	7·3	2·8	189	83	15 606	24 812	12·1	3·4	0·51	0·81
Paediatric medical	14	171	232	73	44 189	5·3	1·7	107	63	11 196	14 094	9·6	4·5	0·25	0·32
Neonatal															
≤750 g	11	126	22	..	1048	21·0	..	6	..	178	..	33·7	..	0·17	..
751–1000 g	11	126	51	..	5648	9·0	..	10	..	339	..	29·5	..	0·06	..
1001–1500 g	11	126	135	..	14 928	9·0	..	13	..	574	..	22·7	..	0·04	..
1501–2500 g	11	126	188	..	17 371	10·8	..	15	..	650	..	23·1	..	0·04	..
>2500 g	11	126	120	..	14 888	8·1	..	14	..	600	..	23·3	..	0·04	..

Data are n, rate per 1000 patient, central line, or urinary catheter days, or ratio. BSI=bloodstream infection. UTI=urinary tract infection. ICU=intensive care unit. CLABSI=central-line-associated bloodstream infection. CAUTI=catheter-associated UTIs. CLUR=central line utilisation ratio. UCUR=urinary catheter utilisation ratio. *Pooled BSI rate=(number of BSIs/number of patient days) × 1000. †Pooled UTI rate=(number of UTIs/number of patient days) × 1000. ‡Pooled CLABSI rate=(number of CLABSIs/number of central line days) × 1000. §Pooled CAUTI rate=(number of CAUTIs/number of urinary catheter days) × 1000. ¶CLUR=number of central line days/number of patient days. ||UCUR=number of urinary catheter days/number of patient days.

Table 4: **Pooled BSI and UTI rates and device utilisation ratios by ICU type**

	All bloodstream infections*		CLABSI*		All UTIs†		CAUTI†	
	Rank	Pathogens (n=2828)	Rank	Pathogens (n=1341)	Rank	Pathogens (n=809)	Rank	Pathogens (n=773)
Klebsiella spp‡	1	701 (24·8%)	1	295 (22·0%)	4	108 (13·3%)	4	99 (12·8%)
Acinetobacter spp	2	601 (21·3%)	2	252 (18·8%)	6	42 (5·2%)	6	41 (5·3%)
Candida spp	3	333 (11·8%)	3	165 (12·3%)	1	238 (29·4%)	1	229 (29·6%)
Staphylococcus spp	4	248 (8·8%)	7	85 (6·3%)	14	3 (0·4%)	14	3 (0·4%)
Enterococcus spp	5	208 (7·4%)	6	100 (7·5%)	2	147 (18·2%)	2	141 (18·2%)
Pseudomonas spp	6	190 (6·7%)	5	107 (8·0%)	5	64 (7·9%)	5	64 (8·3%)
Escherichia spp	7	143 (5·1%)	8	61 (4·5%)	3	142 (17·6%)	3	133 (17·2%)
Burkholderia spp	8	122 (4·3%)	4	110 (8·2%)	15	1 (0·1%)	15	1 (0·1%)
Enterobacter spp	8	84 (3·0%)	9	51 (3·8%)	10	9 (1·1%)	10	9 (1·2%)
Citrobacter spp	10	41 (1·4%)	11	20 (1·5%)	8	11 (1·4%)	10	9 (1·2%)
Proteus spp	14	11 (0·4%)	14	5 (0·4%)	8	11 (1·4%)	8	11 (1·4%)
Providencia spp	27	1 (<0·1%)	18	1 (0·1%)	7	14 (1·7%)	7	14 (1·8%)
All other pathogens	..	145 (5·1%)	..	89 (6·6%)	..	19 (2·3%)	..	19 (2·5%)

Data are n (%). ICU=intensive care unit. UTI=urinary tract infection. CLABSI=central-line-associated bloodstream infection. CAUTI=catheter-associated UTIs. *Includes adult, paediatric, and neonatal ICUs. †Includes adult and paediatric ICUs. ‡Includes *Klebsiella aerogenes* (formerly *Enterobacter aerogenes*).

Table 5: **Commonly reported pathogens in bloodstream infections and UTIs**

AST results from bloodstream infection and UTI case report forms were used to identify resistance phenotypes of concern (table 6). High levels of resistance to at least one carbapenem were found in HAIs caused by *Klebsiella* spp (bloodstream infections 72·4%; UTIs 76·3%), *Escherichia coli* (bloodstream infections 58·0%; UTI 62·0%), *Acinetobacter* spp (bloodstream infections 77·2%; UTIs 75·7%), and *Pseudomonas* spp (bloodstream infections 63·7%; UTIs 71·9%). Among these four pathogens, the proportion of bloodstream infections that were both carbapenem and colistin resistant ranged from 2·1% (*E coli*) to 8·5% (*Klebsiella* spp); this phenotype was only seen in UTIs with *E coli* (10·0%). Reduced susceptibility to extended spectrum cephalosporins and resistance to fluoroquinolones was common in HAIs caused by these four Gram-negative pathogens.

Discussion

Data from the early implementation of India's first standardised HAI surveillance system in a network of tertiary-level public and private hospitals show high infection rates and very high levels of concerning antibiotic resistance. The HAI surveillance network has been successful due to its to strong local ownership, commitment, and coordination at the national and facility levels, and its modified surveillance protocols that adjust

	All bloodstream infections			CLABSI			All UTI			CAUTI		
	Isolates reported	Isolates tested	Resistant isolates	Isolates reported	Isolates tested	Resistant isolates	Isolates reported	Isolates tested*	Resistant isolates	Isolates reported	Isolates tested*	Resistant isolates
Staphylococcus aureus	198	..	..	59	..	..	3	..	..	3	..	..
Meticillin†	..	108	76 (70·4%)	..	36	30 (83·3%)	..	2	NC	..	2	NC
Vancomycin	..	119	2 (1·7%)	..	41	1 (2·4%)	..	3	NC	..	3	NC
Klebsiella spp	701	..	..	295	..	..	108	..	..	99	..	..
Carbapenems‡	..	689	499 (72·4%)	..	288	206 (71·5%)	..	97	74 (76·3%)	..	89	68 (76·4%)
Colistin	..	457	41 (9·0%)	..	189	17 (9·0%)	..	62	6 (9·7%)	..	56	5 (8·9%)
Carbapenems and colistin	..	457	39 (8·5%)	..	186	15 (8·1%)	..	60	6 (10·0%)	..	54	5 (9·3%)
Extended spectrum cephalosporins§	..	667	596 (89·4%)	..	279	250 (89·6%)	..	100	88 (88·0%)	..	91	80 (87·9%)
Escherichia coli	143	..	..	61	..	..	142	..	..	133	..	..
Carbapenems‡	..	143	83 (58·0%)	..	59	43 (72·9%)	..	129	80 (62·0%)	..	121	75 (62·0%)
Colistin	..	95	2 (2·1%)	..	45	1 (2·2%)	..	73	0	..	73	0
Carbapenems and colistin	..	95	2 (2·1%)	..	45	1 (2·2%)	..	72	0	..	72	0
Extended spectrum cephalosporins§	..	134	119 (88·8%)	..	57	52 (91·2%)	..	128	113 (88·3%)	..	120	106 (88·3%)
Fluoroquinolones¶	..	139	113 (81·3%)	..	57	53 (93·0%)	..	125	114 (91·2%)	..	118	110 (93·2%)
Acinetobacter spp	601	..	..	252	..	..	42	..	..	41	..	..
Carbapenems‖	..	592	457 (77·2%)	..	247	190 (76·9%)	..	37	28 (75·7%)	..	37	27 (73·0%)
Colistin	..	346	17 (4·9%)	..	144	9 (6·3%)	..	22	NC	..	21	NC
Carbapenems and colistin	..	344	11 (3·2%)	..	142	5 (3·5%)	..	20	NC	..	19	NC
Pseudomonas spp	190	..	..	107	..	..	64	..	..	64	..	..
Carbapenems‖	..	157	100 (63·7%)	..	106	56 (52·8%)	..	64	46 (71·9%)	..	64	46 (71·9%)
Colistin	..	108	5 (4·6%)	..	56	4 (7·1%)	..	35	1 (2·9%)	..	35	1 (2·9%)
Carbapenems and colistin	..	106	4 (3·8%)	..	55	1 (1·8%)	..	35	0	..	35	0
Extended spectrum cephalosporins**	..	188	109 (58·0%)	..	105	53 (50·5%)	..	51	42 (82·4%)	..	51	42 (82·4%)
Fluoroquinolones††	..	178	95 (53·4%)	..	107	48 (44·9%)	..	54	43 (79·6%)	..	54	43 (79·6%)
Aminoglycosides‡‡	..	187	119 (63·6%)	..	105	60 (57·1%)	..	64	49 (79·6%)	..	64	49 (76·6%)

Data are n or n (%). UTI=urinary tract infection. CLABSI=central-line-associated bloodstream infection. CAUTI=catheter-associated UTIs. NC=not calculated. *Percentage of resistance was only calculated when at least 30 isolates were tested against the antibiotic or class. †Resistant to cefoxitin or oxacillin. ‡Resistant to doripenem, ertapenem, imipenem, or meropenem. §Resistant or intermediate to cefepime, cefotaxime, ceftazidime, or ceftriaxone. ¶Resistant to ciprofloxacin, levofloxacin, or moxifloxacin. ||Resistant to doripenem, imipenem, or meropenem. **Resistant or intermediate to cefepime or ceftazidime. ††Resistant to ciprofloxacin or levofloxacin. ‡‡Resistant or intermediate to amikacin, gentamicin, or tobramycin.

Table 6: **Antimicrobial resistance patterns in select pathogens in bloodstream infections and UTIs**

for the resources available in hospitals in India. Continued surveillance with these methods will be crucial to track changes as prevention initiatives are emphasised.

A concerning number of HAIs reported to the surveillance network were caused by pathogens exhibiting concerning antimicrobial resistance phenotypes, as seen in other studies from India.[13,24–26] At least 10% of the bloodstream infections reported with *Candida* spp were caused by *C auris*. Carbapenem resistance in *E coli*, *Acinetobacter* spp, *Klebsiella* spp, and *Pseudomonas* spp reported in CLABSIs ranged from 53% (*Pseudomonas* spp) to 77% (*Acinetobacter* spp) and from 62% (*E coli*) to 76% (*Klebsiella* spp) in CAUTIs. Even though 18 facilities did not routinely do broth microdilution for colistin susceptibility testing, we still found several organisms resistant to both carbapenems and colistin among the sites that did do this testing reliably. The prevalence of concerning resistance phenotypes shows the crucial need to better understand the drivers of antimicrobial resistance in these hospitals and the importance of multimodal HAI prevention strategies that include infection prevention and control and antimicrobial stewardship efforts.

The high rate of health-care-associated bloodstream infections in neonatal ICUs was striking. High CLABSI rates were reported for all birthweight categories in neonatal ICUs, with the highest rate (33·7 per 1000 central line days) and central line utilisation in the lowest birthweight category, similar to the results of other large surveillance studies in LMICs.[2,25] It is possible that our case definition misclassifies any secondary bloodstream

infections in these patients as having CLABSIs, as many small infants require central lines for vascular access and taking cultures from other body sites is often not possible. However, implementing core infection prevention practices and focused efforts to prevent neonatal infections should be prioritised; focusing on CLABSI prevention, particularly in the lowest birthweight infants, might be an important starting strategy if resources do not allow comprehensive CLABSI prevention programmes. Further investigation to evaluate the high incidence among neonates is warranted.

We found a high proportion of primary device-associated infections, supporting the rationale for prevention initiatives. 3359 health-care-associated bloodstream infections and UTIs were reported to the network during this 18-month period, including device-associated and non-device associated infections. Of the bloodstream infections reported, 74% were classified as primary, a higher proportion than previous single-centre studies in India that report on all health-care-associated bloodstream infections.[24,27] Device-associated infections were common, as 96% of UTIs were classified as CAUTIs and 54% of bloodstream infections were classified as CLABSIs. A substantial portion of bloodstream infections and UTIs can be prevented through efforts to improve insertion and maintenance of indwelling devices.

Aggregate data from network hospitals are now being used to evaluate the effect of coordinated HAI prevention activities across hospitals. A major prevention priority is the assessment and focused implementation of CLABSI prevention activities across network sites using a bundle of resource-appropriate prevention strategies developed by the network. Hospitals participating in the network are using local surveillance data to assess their facility-specific HAI prevention progress over time and to identify areas to prioritise with scarce resources through quality improvement approaches.[28] As the network grows and receives more data, it can eventually produce representative data for comparisons and benchmarking of facility-level performance. To date, several outbreaks have been identified and contained through use of data from the surveillance network, including an outbreak of colistin-resistant *Klebsiella pneumoniae* in network hospitals[29] and a large outbreak of bloodstream infections caused by *Burkholderia cepacia*.[30]

There are at least seven limitations to the data generated by the surveillance network. First, hospitals participating in this network are not representative of all hospitals in India; our results might not be generalisable. Second, to streamline identification of HAIs and to capture infections most likely to be prevented by infection prevention and control bundles in ICUs, the surveillance only captures HAIs in patients admitted to a subset of a hospital's ICUs for at least 2 days; it is not inclusive of all HAIs in network hospitals. Third, the network's bloodstream infection and UTI case definitions have not been compared with those used in more established surveillance systems (eg, NHSN)—the comparability of rates between these two systems is not fully understood, although sufficient similarities might make the rates somewhat comparable. Additional studies to assess the sensitivity and specificity of these case definitions are planned. Fourth, culturing practices have a substantial effect on identification and classification of HAIs and the detection of antimicrobial resistance in this surveillance network, and they vary across hospitals and physicians within hospitals. Our bloodstream infection case definition classifies primary and secondary bloodstream infections based on matching organisms in the blood and any in other body site; therefore, the number of cultures that physicians order from non-blood sites can influence CLABSI rates. Additionally, if resources allow cultures only for some patients, (eg, patients who fail empirical therapy), resistance in reported bloodstream infections and UTIs might be overestimated; although, HAI rates are likely to be underestimated. Fifth, challenges in elucidating UTI symptoms from catheterised and ventilated patients, along with poor documentation of temperature and other symptoms in medical records, might have limited the number of patients with UTIs who met the case definition criteria. Sixth, only a subset of facilities did broth microdilution testing for colistin sensitivity. Since facilities reported colistin AST results regardless of the method used, true rates of colistin resistance might not be reflected; although, colistin resistance was detected in facilities that do broth microdilution. Seventh, despite efforts to administer tools during site visits to ensure adherence to surveillance protocols and standardisation of data reported by each site, variations in site-level HAI identification and reporting might still exist.

This network has implemented HAI surveillance with a standardised, resource-appropriate methodology across hospitals, allowing for data to be compiled and analysed at an aggregate network level. Health-care-associated bloodstream infections and UTIs, particularly antibiotic-resistant infections, are major problems across network hospitals, and focused efforts targeting prevention of priority HAIs are underway. Data produced by this network can be used as a foundation for developing a better understanding of the burden of HAIs across India.

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Contributors

PMat, KW, PS, NG, AS, and KL conceptualised the study. PMat, PMal, PS, NG, AS, and KL developed the study methodology. PMat, AC, PRa, MB, PRu, VB, CR, VLN, VT, VV, CM, VD, KP, CW, SBh, TK, BB, SS, RN, RR, SBa, BAF, KSD, PD, NK, PV, PB, and RGa did the site-level investigation, supervision, and project administration. PMat, PMal, KW, PS, SG, LK, NG, AS, DV, VS, KL, and RGu supported network-level supervision and project administration. PMat, AL, and KW supported data curation, did the data analysis, and directly accessed and verified the underlying data in the manuscript. PMat and PMal created the original manuscript draft. All authors participated equally in reviewing and editing the manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

Deidentified datasets relevant to this study can be made available upon request following submission of a proposal to the corresponding author and review and approval by network collaborators. Study protocols and affiliated reference materials are available on the HAI surveillance network's website at www.haisindia.com.

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