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Data Elements and Validation Methods Used for Electronic Surveillance of Healthcare-Associated Infections: A Systematic Review

Kenrick D Cato, RN, PhD¹, Bevin Cohen, MPH^{1,2}, and Elaine Larson, RN, PhD, FAAN, CIC^{1,2}

¹School of Nursing, Columbia University, New York, NY

²Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY, USA

Abstract

Objective—This study describes the primary data sources, data elements, and validation methods currently used in electronic surveillance systems (ESS) for identification and surveillance of healthcare-associated infections (HAIs), and compares these data elements and validation methods with recommended standards.

Methods—Using PRISMA guidelines, a PubMed and manual search was conducted to identify research articles describing ESS for identification and surveillance of HAIs published from January 1, 2009 through August 31, 2014. Selected articles were evaluated to determine what data elements and validation methods were included.

Results—Among the 509 articles identified in the original literature search, 30 met the inclusion criteria. While the majority of studies (83%) used recommended data sources and validated the numerator (80%), only 10 percent of studies performed external and internal validation. In addition, there was variation in ESS data formats used.

Conclusions—The findings of this review suggest that the majority of ESS for HAI surveillance are using standard definitions, but the lack of widespread internal data, denominator, and external validation in these systems reduces the reliability of their findings. Additionally, advanced programming skills are required to create, implement and maintain these systems and to reduce the variability in data formats.

Keywords

Electronic Surveillance System; Healthcare Associated Infection; Automated Surveillance

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Corresponding Author: Kenrick D Cato, RN, PhD, Columbia University School of Nursing, 617 W. 168th Street, New York, New York, 10032, Kdc2110@columbia.edu.

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INTRODUCTION

For the past three decades, surveillance has been recognized as the cornerstone of effective infection prevention and control programs¹, but traditional manual surveillance methods are labor intensive and limited by inter-observer variability². To address these issues, the infection prevention community has pursued the development of automated electronic surveillance systems (ESS). While ESS using electronically available patient data have been found to be accurate and potentially time saving^{3–5}, their performance is not consistent across settings⁶. The performance of ESS often depends on implementation issues related to data sources and data capture⁷. This review utilizes an adapted framework⁸ to 1) describe primary data sources, data elements, and validation methods currently used in ESS for identification and surveillance of healthcare-associated infections (HAIs), and 2) compare these data elements and validation methods with recommended standards.

METHODS

Search strategies and information sources

Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (<http://www.prisma-statement.org/>) as a guide, we conducted a systematic search of published literature that evaluated ESS for HAIs. The PubMed system was used to search for publications indexed by Medline from January 1, 2009 through August 31, 2014. Manual searches were also performed by scanning the bibliographies of eligible original research papers and systematic reviews.

Eligibility criteria and study selection

Selected articles had to describe an automated system that performed electronic HAI surveillance, relevant data sources used in the system, and any system validation performed. Studies that used the electronic health record as solely a means for conducting chart review were excluded, as well as those that investigated predictive risk modeling for HAI. We used the filters 'human', 'abstract', and 'English language' on all searches. Table 1 summarizes the PubMed search query.

Assessment of studies

To ensure articles matched the eligibility criteria, titles and abstracts were evaluated independently by each author and discrepant cases were settled by consensus. Full text of the remaining articles were then reviewed independently by each author to verify that they met the inclusion criteria. After articles that met the inclusion criteria were identified, they were assessed utilizing a modified framework originally developed by Woeltje and colleagues⁸. The first three articles were independently assessed and then discussed by all three authors, and any discrepancies were resolved by consensus. The remaining articles were abstracted by one of the three authors using an assessment framework.

The assessment framework developed by Woeltje, et al.⁸ had two main components. First, for each of five types of infection, recommended data elements for ESS were outlined based on National Healthcare Safety Network definitions for HAI surveillance (<http://>

www.cdc.gov/nhsn/pdfs/pscmanual/17pscnosinfdef_current.pdf). These included central line-associated bloodstream infection (CLABSI), catheter-associated urinary tract infection (CAUTI), surgical site infection (SSI), ventilator-associated event (VAC, IVAC), MDRO module, and *Clostridium difficile* module. We added bloodstream infection (BSI), urinary tract infection (UTI), ventilator-associated pneumonia (VAP), and pneumonia (PNU) to the list of HAI because these were also investigated in the articles we reviewed. Second, four key concepts for describing data validation were recommended: internal and external validation and validation of numerator and denominator⁸. Based on this framework, we evaluated each article to determine whether all recommended data elements were included and whether recommended validations were performed. The Woeltje, et al. framework was modified only for surgical site infections, for which it was decided that an ESS would not require both procedure and diagnostic codes because there is considerable overlap between the two; thus this data element was considered present if either type of code was used.

Results

As Figure 1 illustrates, 509 articles were initially identified (Table 1 lists the full search text). After removing duplicate citations and limiting articles to those with available abstracts, 383 abstracts were screened. An additional 77 were excluded during title and abstract review, primarily because they did not pertain to automated ESS. Full text assessment of 35 articles resulted in 30 final studies that met inclusion criteria.

Table 2 provides a summary of each study reviewed, which included an array of HAIs: BSI=10 and CLABSI=5; UTI=7 and CA-UTI=7; SSI=5; MDRO=3; any ventilator associated events=1 and PNU=2; and *C. difficile*=3. The majority of studies, 83%, used the recommended HAI-specific data sources in their ESS.

The articles reviewed did not always report how clinical facts (e.g. laboratory results, diagnosis, medications administer) were annotated and the corresponding vocabularies used to format the related data. However, there was variation in data formats for the studies that did provide a detailed description of data used by their ESS. These formats varied from unstructured, non-coded, and institution-specific coded data to internationally and nationally adopted formats like ICD-9. To determine antibiotics administered, textual medication names^{9–11}, and institution-specific codes^{12–14} formats were used. ICD-9^{4,9–11,15–19}, SNOMED-CT^{20–22} and free text from notes were used to determine hospital billing diagnosis and procedures^{10,11,17,21}. Microbiology results were formatted in institution-specific codes^{10,11,13,14,17}, textual results^{3–5,9,12,16,18,22–30}, and LOINC²² codes.

Validation performed

Validation of the numerator was performed most often (80%, 24/30 studies). Checking of the actual data with an independent data source, also referred to as internal validation, was done in 33% (10/30) of the studies. External validation, e.g., having an external organization validate the ESS findings, was not used in any of the studies in our sample. Ten percent of the studies (3/30) reported having validated the denominator.

Discussion

The ideal ESS would be fully automated and accurately identify infections without human input. The goal of our literature review was to assess the state of science with regard to electronic surveillance of HAI (e.g., how close we are to full automation). A number of themes emerged from the review relating to data availability, lack of standardized sources of data, the complexity of the ESS and the lack of validation of the surveillance systems.

The increased number of data sources used in ESS reflects the fact that more electronic clinical data continues to become available⁶. However, the fact that 17% of the studies in this review did not use the recommended data suggests that availability of relevant data is still one gap that must be filled before fully automated surveillance of HAI is possible.

The fact that a majority of studies utilized the recommended data elements to define an HAI is encouraging. Still, it is important to note that, for example, even though all of the ESS utilized microbiology laboratory results, there was great variability in the structure of the actual results. This lack of standardization of data is an impediment to having ESS that can be implemented uniformly across settings. Furthermore, lack of uniformity in data input increases the complexity of the systems and the required resources to implement and maintain these systems.

In our review most of the studies were conducted in academic medical centers, Veteran's Administration hospitals, and one large health maintenance organization (HMO). This finding reflects that fact that only institutions with considerable financial resources can afford to implement these systems. Moreover, ESS are complex, range in sophistication, but in general they require high level programing and technologic support. Clearly, the specialized work force that is required to support these systems is sorely lacking^{31,32}. The creation, implementation and management of ESS systems require individuals who understand nuances of clinical data and its analytical techniques, and have ability to extract and transform standard and non-standard data sources.

None of the studies in this review met the criteria of having internal, external, denominator and numerator validation. It is important to note that denominator validation is often not applicable and feasible to calculate for the HAIs that are applicable to an entire inpatient population. While the logistics of accomplishing the task of validating the data are daunting, validation is vital and must be performed on these systems³³. Research has indicated that ESS studies which have performed the requisite numerator, denominator and/or external validation found high variability in sensitivity/specificity^{7,34}. In addition, studies have also highlighted the lack of completeness³⁵ and bias^{36,37} of electronic patient data.

This literature review was limited by the inclusion of only articles written in English with abstracts, and use of a single database with a limited number of search terms. Therefore, some articles pertaining to the topic could have been missed. Nonetheless, our findings present the state of the science in ESS research and point to important future directions for continued investigation. In summary, we recommend that future ESS HAI surveillance focus on obtaining high-quality data, employing dedicated programmers with advanced skills, and performing more thorough validation.

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References

1. Haley RW, Culver DH, White JW, et al. The efficacy of infection surveillance and control programs in preventing nosocomial infections in US hospitals. *American journal of epidemiology*. 1985; 121:182–205. [PubMed: 4014115]
2. Lin MY, Hota B, Khan YM, et al. Quality of traditional surveillance for public reporting of nosocomial bloodstream infection rates. *JAMA: the journal of the American Medical Association*. 2010; 304:2035–41.
3. Dubberke ER, Nyazee HA, Yokoe DS, et al. Implementing automated surveillance for tracking *Clostridium difficile* infection at multiple healthcare facilities. *Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America*. 2012; 33:305–8.
4. Leal J, Gregson DB, Ross T, Flemons WW, Church DL, Laupland KB. Development of a novel electronic surveillance system for monitoring of bloodstream infections. *Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America*. 2010; 31:740–7.
5. Adlassnig KP, Berger A, Koller W, et al. Healthcare-associated infection surveillance and bedside alerts. *Studies in health technology and informatics*. 2014; 198:71–8. [PubMed: 24825687]
6. Kashiouris M, O'Horo JC, Pickering BW, Herasevich V. Diagnostic performance of electronic syndromic surveillance systems in acute care: a systematic review. *Applied clinical informatics*. 2013; 4:212–24. [PubMed: 23874359]
7. de Bruin JS, Seeling W, Schuh C. Data use and effectiveness in electronic surveillance of healthcare associated infections in the 21st century: a systematic review. *Journal of the American Medical Informatics Association*. 2014; 21:942–51. [PubMed: 24421290]
8. Woeltje KF, Lin MY, Klompas M, Wright MO, Zuccotti G, Trick WE. Data requirements for electronic surveillance of healthcare-associated infections. *Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America*. 2014; 35:1083–91.
9. Knepper BC, Young H, Jenkins TC, Price CS. Time-saving impact of an algorithm to identify potential surgical site infections. *Infection Control & Hospital Epidemiology*. 2013; 34:1094–8. [PubMed: 24018927]
10. Apte M, Landers T, Furuya Y, Hyman S, Larson E. Comparison of two computer algorithms to identify surgical site infections. *Surgical infections*. 2011; 12:459–64. [PubMed: 22136489]
11. Apte M, Neidell M, Furuya EY, Caplan D, Glied S, Larson E. Using electronically available inpatient hospital data for research. *Clinical and translational science*. 2011; 4:338–45. [PubMed: 22029805]
12. Shepard J, Hadhazy E, Frederick J, et al. Using electronic medical records to increase the efficiency of catheter-associated urinary tract infection surveillance for National Health and Safety Network reporting. *American journal of infection control*. 2014; 42:e33–6. [PubMed: 24581026]
13. Tseng YJ, Wu JH, Lin HC, et al. Rule-based healthcare-associated bloodstream infection classification and surveillance system. *Studies in Health Technology & Informatics*. 2013; 186:145–9. [PubMed: 23542986]
14. Tseng YJ, Wu JH, Ping XO, et al. A Web-based multidrug-resistant organisms surveillance and outbreak detection system with rule-based classification and clustering. *Journal of Medical Internet Research*. 2012; 14:e131. [PubMed: 23195868]
15. Inacio MC, Paxton EW, Chen Y, et al. Leveraging electronic medical records for surveillance of surgical site infection in a total joint replacement population. *Infection Control & Hospital Epidemiology*. 2011; 32:351–9. [PubMed: 21460486]

16. Klein Klouwenberg PM, van Mourik MS, Ong DS, et al. Electronic implementation of a novel surveillance paradigm for ventilator-associated events. Feasibility and validation American Journal of Respiratory & Critical Care Medicine. 2014; 189:947–55.
17. Landers T, Apte M, Hyman S, Furuya Y, Glied S, Larson E. A comparison of methods to detect urinary tract infections using electronic data. Joint Commission journal on quality and patient safety/Joint Commission Resources. 2010; 36:411–7. [PubMed: 20873674]
18. Leth RA, Norgaard M, Uldbjerg N, Thomsen RW, Moller JK. Surveillance of selected post-caesarean infections based on electronic registries: validation study including post-discharge infections. The Journal of hospital infection. 2010; 75:200–4. [PubMed: 20381909]
19. Schmiedeskamp M, Harpe S, Polk R, Oinonen M, Pakyz A. Use of International Classification of Diseases, Ninth Revision, Clinical Modification codes and medication use data to identify nosocomial *Clostridium difficile* infection. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2009; 30:1070–6.
20. Branch-Elliman W, Strymish J, Gupta K. Development and validation of a simple and easy-to-employ electronic algorithm for identifying clinical methicillin-resistant *Staphylococcus aureus* infection. Infection Control & Hospital Epidemiology. 2014; 35:692–8. [PubMed: 24799646]
21. FitzHenry F, Murff HJ, Matheny ME, et al. Exploring the frontier of electronic health record surveillance: the case of postoperative complications. Medical care. 2013; 51:509–16. [PubMed: 23673394]
22. Benoit SR, McDonald LC, English R, Tokars JI. Automated surveillance of *Clostridium difficile* infections using BioSense. Infection Control & Hospital Epidemiology. 2011; 32:26–33. [PubMed: 21128815]
23. Adlassnig KP, Blacky A, Koller W. Artificial-intelligence-based hospital-acquired infection control. Studies in health technology and informatics. 2009; 149:103–10. [PubMed: 19745475]
24. Choudhuri JA, Pergamit RF, Chan JD, et al. An electronic catheter-associated urinary tract infection surveillance tool. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2011; 32:757–62.
25. de Bruin JS, Blacky A, Koller W, Adlassnig KP. Validation of fuzzy sets in an automated detection system for intensive-care-unit-acquired central-venous-catheter-related infections. Studies in Health Technology & Informatics. 2013; 192:215–8. [PubMed: 23920547]
26. De Bus L, Diet G, Gadeyne B, et al. Validity analysis of a unique infection surveillance system in the intensive care unit by analysis of a data warehouse built through a workflow-integrated software application. Journal of Hospital Infection. 2014; 87:159–64. [PubMed: 24856115]
27. Harron K, Goldstein H, Wade A, Muller-Pebody B, Parslow R, Gilbert R. Linkage, evaluation and analysis of national electronic healthcare data: application to providing enhanced blood-stream infection surveillance in paediatric intensive care. PLoS ONE [Electronic Resource]. 2013; 8:e85278.
28. Peterson KE, Hacek DM, Robicsek A, Thomson RB Jr, Peterson LR. Electronic surveillance for infectious disease trend analysis following a quality improvement intervention. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2012; 33:790–5.
29. Wald HL, Bandle B, Richard A, Min S. Accuracy of electronic surveillance of catheter-associated urinary tract infection at an academic medical center. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2014; 35:685–91.
30. Woeltje KF, McMullen KM, Butler AM, Goris AJ, Doherty JA. Electronic surveillance for healthcare-associated central line-associated bloodstream infections outside the intensive care unit. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2011; 32:1086–90.
31. Hersh, W.; Wright, A. What Workforce is Needed to Implement the Health Information Technology Agenda?. Analysis from the HIMSS Analytics™ Database; AMIA Annual Symposium Proceedings; 2008; American Medical Informatics Association; p. 303
32. Hersh WR, Weiner MG, Embi PJ, et al. Caveats for the use of operational electronic health record data in comparative effectiveness research. Medical care. 2013; 51:S30–S7. [PubMed: 23774517]

33. Arnold KE, Thompson ND. Building Data Quality and Confidence in Data Reported to the National Healthcare Safety Network. *Infection Control and Hospital Epidemiology*. 2012; 33:446–8. [PubMed: 22476269]
34. Haut ER, Pronovost PJ. Surveillance bias in outcomes reporting. *JAMA: the journal of the American Medical Association*. 2011; 305:2462–3.
35. Weiskopf NG, Hripcsak G, Swaminathan S, Weng C. Defining and measuring completeness of electronic health records for secondary use. *Journal of biomedical informatics*. 2013; 46:830–6. [PubMed: 23820016]
36. Hripcsak G, Knirsch C, Zhou L, Wilcox A, Melton G. Bias associated with mining electronic health records. *Journal of biomedical discovery and collaboration*. 2011; 6:48–52. [PubMed: 21647858]
37. van Mourik MSM, Troelstra A, van Solinge WW, Moons KGM, Bonten MJM. Automated Surveillance for Healthcare-Associated Infections: Opportunities for Improvement. *Clinical Infectious Diseases*. 2013; 57:85–93. [PubMed: 23532476]
38. Herasevich V, Pickering BW, Dong Y, Peters SG, Gajic O. Informatics Infrastructure for Syndrome Surveillance, Decision Support, Reporting, and Modeling of Critical Illness. *Mayo Clinic Proceedings*. 2010; 85:247–54. [PubMed: 20194152]
39. Lo YS, Lee WS, Liu CT. Utilization of electronic medical records to build a detection model for surveillance of healthcare-associated urinary tract infections. *Journal of Medical Systems*. 2013; 37:9923. [PubMed: 23321977]
40. Venable A, Dissanaik S. Is automated electronic surveillance for healthcare-associated infections accurate in the burn unit? *Journal of Burn Care & Research*. 2013; 34:591–7. [PubMed: 24121803]
41. Wu J-H, Chen Y-C, Hsieh S-h, et al. Real-time Automated MDRO Surveillance System. *BIOCOMP*. 2009:764–9.
42. Blacky A, Mandl H, Adlassnig KP, Koller W. Fully Automated Surveillance of Healthcare-Associated Infections with MONI-ICU. A Breakthrough in Clinical Infection Surveillance. *Applied Clinical Informatics*. 2011; 2:365–72. [PubMed: 23616883]

Figure 1.
PubMed search query for automated HAI surveillance systems

Table 1

Search term used for PubMed query

Search Term
((("cross infection"[All Fields] OR "Algorithms"[All Fields] OR "automated surveillance"[All Fields] OR "Automatic Data Processing"[All Fields] OR "Bacteremia/classification"[All Fields] OR "Infection Control"[All Fields] OR "Sentinel Surveillance"[All Fields] OR "Electronic Surveillance System"[All Fields] OR "Surgical Wound Infection"[All Fields] OR "Surgical site infection"[All Fields] OR "Population Surveillance/methods"[All Fields] OR "Hospital Information Systems"[All Fields] OR "Diagnosis, Computer-Assisted"[All Fields] OR "Data Collection/methods"[All Fields] OR "hospital acquired infection"[All Fields] OR "hospital associated infection"[All Fields] OR "healthcare associated infection"[All Fields] OR Fields[All Fields] OR "patient to patient infection"[All Fields] OR "nosocomial infection"[All Fields] OR "catheter related infection"[All Fields] OR "CLABSI"[All Fields] OR "BSI"[All Fields] OR "Urinary Tract Infections"[All Fields] OR "central line associated bloodstream infection"[All Fields]) AND ("electronic health record"[All Fields] OR "EHR"[All Fields] OR "EMR"[All Fields] OR "electronic medical record"[All Fields] OR "computerized medical record"[All Fields])AND "2009/01/01"[PDAT]: "2014/09/01"[PDAT]))

Table 2

Data elements and validation used by ESS studies

Group	Article	Study setting and size	HAI types	Data sources used	Used recommended data sources ⁸	Validation performed
	Benoit et al 2011 ²²	Thirty-four hospitals, 4,585 patients, 12 states	C. difficile	Microbiology cultures, ADT	Yes	None
	Branch-Elliman 2014 ²⁰	Five acute care VA hospitals	MDRO	Microbiology cultures	No	None
	Choudhuri et al 2014 ²⁴	Teaching hospital 136 patients	CAUTI	Microbiology cultures, ADT, vital signs, urinalysis	Yes	Internal, Numerator,
	De Bus 2014 ²⁶	University hospital 14 bed MICU, 22 bed SICU, 876 admissions	UTI, BSI	Microbiology cultures, ADT, vital signs, urinalysis	Yes	Internal, Denominator Numerator
	Dubberke et al 2012 ³	Four hospitals	C. difficile	Microbiology cultures, ADT	Yes	Numerator
	FitzHenry et al 2013 ²¹	Six VA hospitals, 33,565 patients	SSI	Microbiology cultures, ADT	Yes	Numerator
	Harron et al 2013 ²⁷	109,654 pediatric inpatient records	BSI	Microbiology cultures, ADT	Yes	Internal, Numerator
	Herasevich et al 2010 ³⁸	Academic medical center, 204 bed ICU	BSI	Microbiology cultures, ADT	Yes	Internal, Numerator
	Inacio et al 2011 ¹⁵	Large HMO	SSI	Microbiology cultures, ADT, hospital procedure codes, hospital diagnosis codes	Yes	Numerator, Denominator
	Klein et al 2014 ¹⁶	Tertiary referral centers 2,080 patients	VAC, VAE	Microbiology cultures, ADT, vital signs, presence of endotracheal intubation device, laboratory (white blood cell count), ventilator settings (PEEP, FiO2 antimicrobial use)	Yes	Numerator
	Knepper et al 2013 ⁹	Academic safety-net hospital, 2,449 surgical procedures	SSI	Microbiology cultures, ADT, antibiotic administration, hospital procedure codes, hospital diagnosis codes	Yes	Numerator
	Leal et al 2010 ⁴	Regional hospital, 306 patients	BSI	Microbiology cultures, ADT	Yes	Numerator
	Leth et al 2010 ¹⁸	1504 C-Section cases	UTI	Microbiology cultures, ADT, vital signs, urinalysis	Yes	Numerator
	Lo et al 2013 ^{28,39}	Tertiary care teaching hospital, 730-bed	CAUTI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis	Yes	Numerator
	Peterson et al 2012 ²⁸	Health system, over 300,000 patients	MDRO	Microbiology cultures, ADT	Yes	Numerator

Group	Article	Study setting and size	HAI types	Data sources used	Used recommended data sources ⁸	Validation performed
	Schmiedeskamp et al 2009	1923,920 inpatient discharges	C. difficile	Microbiology cultures, ADT	Yes	Numerator
	Shepard et al 2014 ¹²	A 583-bed adult tertiary care center, 6,379 urine cultures	CAUTI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis	Yes	Numerator
	Venable et al 2009 ⁴⁰	A 420-bed teaching hospital	CLABSI, CAUTI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis, central venous catheter presence	Yes	Numerator
	Wald et al 2014 ²⁹	A 425-bed university hospital, 1,695 patient visits	CAUTI	Microbiology cultures, ADT, vital signs, urinary catheter present,	Yes	Internal, Numerator
	Woeltje et al 2011 ³⁰	A 1,250-bed tertiary care teaching hospital	CLABSI	Microbiology cultures, ADT	No	Internal, Numerator
National Taiwan U.	Tseng et al 2012 ¹⁴	A 2200-bed teaching hospital	MDRO	Microbiology cultures, ADT	Yes	Numerator
National Taiwan U.	Tseng et al 2013 ¹³	A 2200-bed teaching hospital	BSI	Microbiology cultures, ADT	Yes	Internal, Numerator
National Taiwan U.	Wu et al 2009 ⁴¹	A 2200-bed teaching hospital	MDRO	Microbiology cultures, ADT	Yes	Internal, Numerator
Columbia	Apte, Landers et. al 2011 ¹⁰	Academic medical center 28,956 hospital admissions	SSI	Microbiology cultures, ADT, antibiotic administration, hospital procedure codes	No	Internal, Numerator, Denominator
Columbia	Apte, Neidell et al 2011 ¹¹	Academic medical center 320,000 inpatient discharges	BSI, PNU, SSI, UTI	Microbiology cultures, ADT, urinary catheter present, urinalysis, central venous catheter presence, AD, antibiotic administration,	No	None
Columbia	Landers et al 2010 ¹⁷	Academic medical center 33,834 hospital admissions	UTI	Microbiology cultures, ADT, urinalysis	No	None
MONI	Adlassnig et al 2009 ²³	Teaching hospital 96 ICU beds	UTI, CAUTI, BSI, CLABSI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis, central venous catheter presence	Yes	None
MONI	Adlassnig et al 2014 ⁵	Teaching hospital, 87 adult ICU beds, 46 NICU beds	UTI, CAUTI, BSI, CLABSI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis, central venous catheter presence	Yes	None
MONI	de Bruin et al 2013 ²⁵	Teaching hospital 75 ICU beds	BSI	Microbiology cultures, ADT, vital signs, urinalysis, biochemistry laboratory	Yes	Internal
MONI	Blacky 2011 ⁴²	Teaching hospital 96 ICU patients in 12 ICUs	BSI, CLABSI, PNU, UTI	Microbiology cultures, ADT, vital signs, urinary catheter present, urinalysis, central	Yes	Numerator

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Group	Article	Study setting and size	HAI types	Data sources used	Used recommended data sources ⁸	Validation performed
ICU, intensive care unit; MICU, medical intensive care unit; SICU, surgical intensive care unit; ADT, admission discharge transfer information; BSI, bloodstream infection; UTI, urinary tract infection; CAUTI, catheter-associated urinary tract infection; MDRO, multi-drug resistant organisms; SSI, surgical site infection; VAE, ventilator-associated events; VAP, ventilator-associated pneumonia; PNU, pneumonia						
				venous catheter presence, antibiotic administration venous catheter presence, antibiotic administration		