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Accuracy of administrative data for surveillance of healthcare-associated infections: a systematic review

Maaike S M van Mourik,[1] Pleun Joppe van Duijn,[2] Karel G M Moons,[2] Marc J M Bonten,[1,2] Grace M Lee[3,4]

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For numbered affiliations see end of article.

Correspondence to
Dr Maaike S M van Mourik; M.S.M.vanMourik-2@umcutrecht.nl

ABSTRACT

Objective: Measuring the incidence of healthcare-associated infections (HAI) is of increasing importance in current healthcare delivery systems. Administrative data algorithms, including (combinations of) diagnosis codes, are commonly used to determine the occurrence of HAI, either to support within-hospital surveillance programmes or as free-standing quality indicators. We conducted a systematic review evaluating the diagnostic accuracy of administrative data for the detection of HAI.

Methods: Systematic search of Medline, Embase, CINAHL and Cochrane for relevant studies (1995–2013). Methodological quality assessment was performed using QUADAS-2 criteria; diagnostic accuracy estimates were stratified by HAI type and key study characteristics.

Results: 57 studies were included, the majority aiming to detect surgical site or bloodstream infections. Study designs were very diverse regarding the specification of their administrative data algorithm (code selections, follow-up) and definitions of HAI presence. One-third of studies had important methodological limitations including differential or incomplete HAI ascertainment or lack of blinding of assessors. Observed sensitivity and positive predictive values of administrative data algorithms for HAI detection were very heterogeneous and generally modest at best, both for within-hospital algorithms and for formal quality indicators; accuracy was particularly poor for the identification of device-associated HAI such as central line associated bloodstream infections. The large heterogeneity in study designs across the included studies precluded formal calculation of summary diagnostic accuracy estimates in most instances.

Conclusions: Administrative data had limited and highly variable accuracy for the detection of HAI, and their judicious use for internal surveillance efforts and external quality assessment is recommended. If hospitals and policymakers choose to rely on administrative data for HAI surveillance, continued improvements to existing algorithms and their robust validation are imperative.

Strengths and limitations of this study

- Administrative data algorithms, based on discharge and procedure codes, are increasingly used to facilitate surveillance efforts and derive quality indicators.
- This comprehensive systematic review explicitly distinguished between administrative data algorithms developed for in-hospital surveillance and those for (external) quality assessment.
- All included primary studies were subjected to a thorough methodological quality assessment; this revealed frequent risk of bias in primary studies.
- The diverse nature of primary studies regarding study methods and algorithms precluded the pooling of results in most instances.

INTRODUCTION

Assessment of quality of care and monitoring of patient complications is a key concept in current healthcare delivery systems.[1] Administrative data, and discharge codes in particular, have been used as a valuable source of information to define patient populations, assess severity of disease, determine patient outcomes and detect adverse events, including healthcare-associated infections (HAI).[2–4] In certain instances, administrative data are employed to measure quality of care and govern payment incentives. Examples include patient-safety indicators (PSIs) developed by the USA Agency for Healthcare Quality Research, reduced payment for Healthcare-Associated Conditions (HACs) considered preventable and the expansion of value-based purchasing (VBP) initiatives, both implemented by US federal payers.[5–8] HAI rates reported to the national surveillance networks such as the US National Healthcare Safety Network (NHSN) are often determined from clinical patient information through chart review. Although these more clinical rates are increasingly adopted by quality programmes, administrative data are still a key component of HAI detection for payers and some quality measurement programmes.[4 6]

Nonetheless, many cautionary notes have been raised regarding the accuracy of administrative data for the purpose of HAI surveillance.[1 9–11] Their universal use, ease of accessibility and relative standardisation across settings and time make them attractive for large-scale surveillance and research efforts. On the flip side—inherent to their purpose as a means to organise billing and reimbursement of healthcare—administrative data were not designed for the surveillance of HAI. Hence, when assigning primary and secondary discharge diagnosis codes, other interests may have greater priority, for example, maximising reimbursement for care delivered. In addition, the reliability of diagnosis code assignment depends heavily on adequate clinician documentation and the number of diagnoses in relation to the number of fields available.[3 12]

For the purpose of HAI surveillance, different targeted applications of administrative data algorithms define what measures of concordance are most important. First, they may be used as a case-finder to support within-hospital surveillance efforts, either in isolation or combined with other indicators of HAI such as microbiology culture results or antibiotic dispensing. In this case, sufficient sensitivity may be preferred over positive predictive value (PPV) to identify patients who require manual confirmation of HAI. Alternatively, discharge codes may be used in external quality indicator algorithms that directly determine the occurrence of HAI and thus gauge hospital performance.[3 9 13] In this setting, high PPV of observed signals may be of greater importance than detecting all cases of HAI. The primary objective of this systematic review was to assess the overall accuracy of published administrative data algorithms for the surveillance (ie, detection) of a broad range of HAI. We also determined whether the accuracy of algorithms developed for within-hospital surveillance differs from those meant for external quality evaluation. In addition, we rigorously evaluated the methodological quality of included studies using the QUADAS-2 tool developed for systematic reviews of diagnostic accuracy studies and also assessed the impact of a possible risk of bias.

METHODS

This systematic review includes studies assessing the diagnostic accuracy of administrative data algorithms using discharge and/or procedure codes for detecting HAI. Studies assessing infection or colonisation with specific pathogens (eg, methicillin-resistant *Staphylococcus aureus* or *Clostridium difficile*) were not included as laboratory-based surveillance may be considered more appropriate. The results of this analysis are reported in accordance with PRISMA guidelines.[14] This review did not receive protocol registration.

Search

Medline, EMBASE, the Cochrane database and CINAHL were searched for studies published from 1995 onwards with a query combining representations of administrative data and (healthcare-associated) infections (see online supplementary data 1 S1) with limits set to articles published in English, French or Dutch. The search was performed on 8 March 2012 and closed on 1 March 2013.

Study selection

To define suitability for inclusion, the following criteria were applied: (1) the study assessed concordance between administrative data and HAI occurrence, (2) data included were from 1995 or later as earlier data may be of limited generalisability to current practice, (3) the study did not reflect natural language processing and (4) the study presented original research rather than reviews or duplicated results. Selection of studies was done by a single reviewer (MSMvM), with cross-referencing to detect possibly missed studies. Inclusion was not restricted to specific geographical locations or patient populations, and nor was there a requirement for complete data availability.

Definitions

Administrative data algorithms were considered the index test (ie, the test under investigation). These algorithms consist of a selection of diagnosis and/or procedure codes used for billing or other purposes. The selection of codes within each algorithm was either specific for the study or, in some cases, they were predefined metrics used for payment or quality assessment. The latter group includes PSIs, HACs or the code selection defined by the Pennsylvania Healthcare Cost Containment Council (PHC4); most were used and developed in the USA, but the PSIs have also been used in other countries.[6 15] The reference standard was the presence or absence of HAI as determined by a review of patient clinical records, according to national infection surveillance methods (eg, NHSN), definitions from surgical quality monitoring programmes such as the US Surgical Quality Improvement Program (SQIP) or other definitions.

Quality assessment and data extraction

After selection of studies, quality assessment and data extraction was performed independently by two reviewers (MSMvM, PJvD) using modified QUADAS-2 criteria for quality assessment of diagnostic accuracy studies (see online supplementary table S2 for data extraction forms, details and assumptions).[16 17]

In brief, these criteria evaluate risk of bias and applicability to the review question with respect to methods of patient selection, the index test and the reference standard. In addition, the criteria provide a framework to evaluate risk of bias introduced by (in)complete HAI ascertainment, the so-called 'patient flow'. Points of special attention during the quality assessment were whether HAI ascertainment was blinded to the outcome of the administrative data algorithm and the identification of partial or differential verification patterns. Partial verification occurs when not all patients were assessed for HAI presence (received the reference standard), in a pattern reliant on the result of the index test. In the case of differential verification, not all patients who were evaluated with the index test received the same reference standard. Depending on the pattern of partial and/or differential verification, this may have introduced bias in the observed accuracy estimates of the algorithm under study.[18] Several studies contained multiple types of verification patterns, methods of HAI ascertainment or specifications of administrative data algorithms; quality assessment and data extraction was then applied separately to each so-called comparison. Agreement between observers on methodological quality was reached by discussion.

Analyses

Included studies were stratified by HAI type and by the intended application of the administrative data within the process of HAI surveillance. A distinction was made between algorithms aimed at supporting within-hospital surveillance—either in isolation or in combination with other indicators—and those developed as a means of external quality of care evaluation. In addition, studies were classified by risk of bias based on QUADAS-2 criteria. Forest plots were created depicting the reported sensitivity, specificity, positive and negative predictive values of the administrative data algorithms for HAI detection.

If large enough groups of sufficiently comparable studies with complete two-by-two tables were available, estimates for sensitivity and specificity were pooled using the bivariate method recommended in the Cochrane Handbook for Systematic Reviews of Diagnostic Accuracy.[19 20] This analysis jointly models the distribution of sensitivity and specificity, accounting for correlation between these two outcome measures. There was no formal assessment of publication bias. All analyses were performed using R V.3.0.1 (http://www.r-project.org) and SPSS Statistics 20 (IBM, Armonk, New York, USA).

RESULTS

Study selection

After removal of duplicates, 8478 unique titles were screened for relevance and exclusion criteria were applied to 675 remaining abstracts. Cross-referencing identified four additional articles; in addition, 10 articles were published between the search date and search closure (figure 1). Fifty-seven studies, containing 71 comparisons, were available for the qualitative synthesis and underwent methodological quality assessment.[21–77]

Study characteristics

Study design, selection of the study population, methodology used as reference standard and administrative data specifications varied greatly. This large variability in study characteristics precluded the generation of summary estimates for sensitivity and specificity for most types of HAI. As the reference standard, 35 studies applied NHSN methodology to determine HAI presence, six defined HAI as registered in SQIP, and the remaining studies used clinical or other methods (table 1). Case-definitions were applied by infection preventionists in 24 studies, as well as by trained nurses, physicians or other abstractors. Eighteen studies assessed algorithms for within-hospital surveillance, and a further 15 combined administrative data with other indicators of infection (eg, microbiology culture results or antibiotic use) to detect HAI. Twenty-four studies assessed administrative data algorithms explicitly designed for external quality assessment, such as PSIs or HACs. Only seven studies provided data collected after 2008.[36 45 53 66 69 31 34]

Methodological quality

Figure 2 summarises the risk of bias and applicability concerns for each QUADAS-2 domain (see online supplementary data S3 for details by study; S4 for figures by HAI type). A high risk of bias in the flow component was observed in a considerable fraction of included studies. Ascertainment of HAI status was complete in 37 of 57 studies; in other words, only 65% of studies had the same reference standard applied to all or a random sample of the included patients. Alternative verification patterns were: evaluation of only those patients flagged by administrative data (nine), assessment of patients flagged by either administrative data or another test (eg, microbiological testing) (eight) and reclassification of discrepant cases after a second review. A high risk of bias for the flow component often co-occurred with the inability to extract complete data on diagnostic accuracy, mainly as a result of partial verification. In studies that assessed only the PPV, HAI ascertainment was limited to patients flagged by administrative data; this partial verification in itself was not problematic; however, lack of blinding of assessors may still have introduced an overall risk of bias.

Surgical site infection

Thirty four studies assessed surgical site infection (SSI); most studies identified the population at risk (ie, the denominator) by selecting specific procedure codes from claims data, although a few included all patients admitted to surgical wards. Details on administrative data algorithms are specified in online supplementary table S6. Algorithms in studies applying NHSN methods as a reference standard generally also incorporated diagnosis codes assigned during readmissions to complete the required follow-up duration, and several included follow-up procedures to detect SSI.

Accuracy estimates were highly variable (figure 3A, see online supplementary S5A), also within groups of studies with the same target procedures and intended

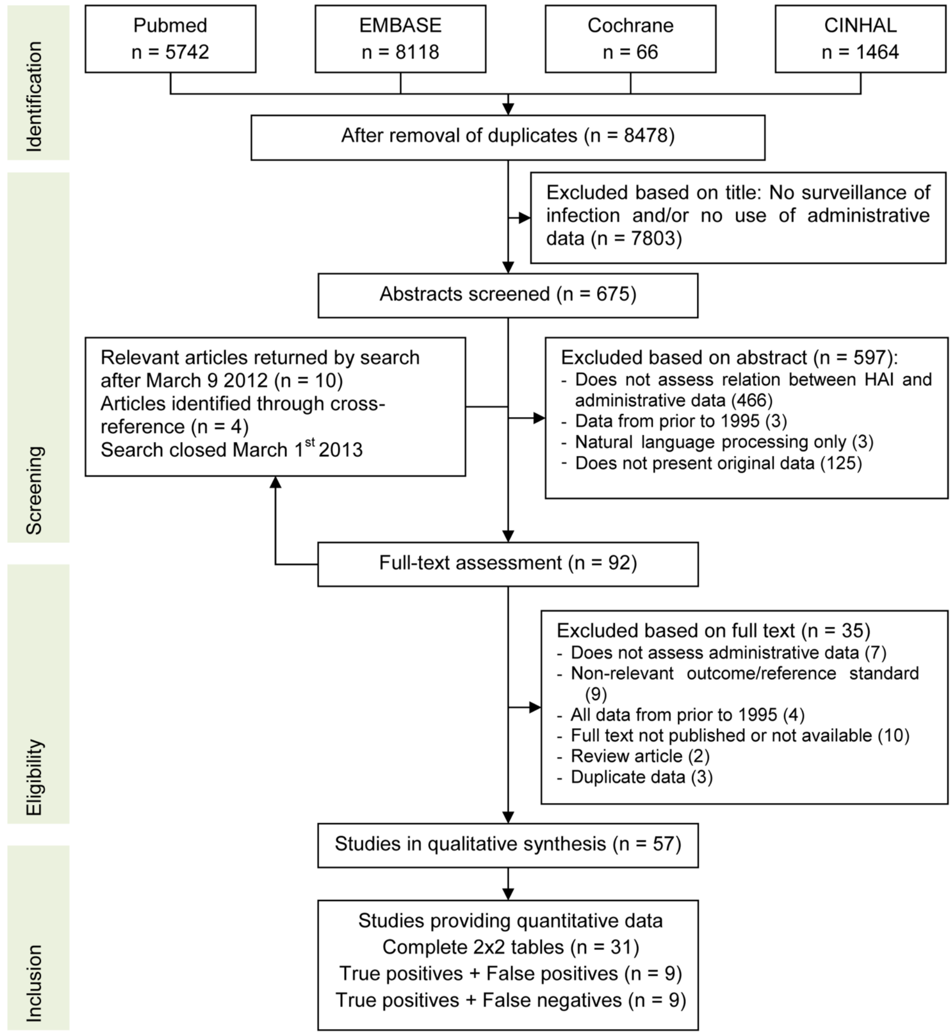

Figure 1 Flow chart of study selection and inclusion. HAI, healthcare-associated infections.

application (range for sensitivity 10–100%, PPV 11–95%). Several studies assessed multiple specifications of administrative data algorithms; as expected, using a broader selection of discharge codes detected more cases of SSI at the cost of lower PPV.[26 47 54] Between studies, there was no apparent relation between the specificity of the codes included and observed accuracy (ICD9 codes 998.5, 996.6 (or equivalent) vs a broader selection, data not shown). Inspection of the forest plots suggests that, in general, studies with a high risk of bias showed a more favourable diagnostic accuracy than those with more robust methodological quality, perhaps with the exception of cardiac procedures.

Bloodstream infections

Of the 24 studies evaluating bloodstream infections (BSI), half focused on central line-associated BSI (CLABSI) and 19 assessed algorithms for external quality assessment. Methods of identifying patients with a central line were very diverse: studies evaluating PSI 7 ('central venous catheter-related BSI') or HAC applied specific discharge codes, whereas other studies only included patients with positive blood cultures[67] or relied on manual surveillance to determine central line presence (see online supplementary table S6).[69] The sensitivity of CLABSI detection was no higher than 40% in all but one study. Notably, only the studies that did not rely on administrative data to determine central line presence achieved sensitivity over 20% (figure 3B and see online supplementary S5B). The sensitivity of administrative data algorithms for detecting BSI was slightly higher. The pooled sensitivity of PSI 13 ('post-operative sepsis') in studies using SQIP methods as a reference standard was 17.0% (95% CI 6.8% to 36.4%) with a specificity of 99.6% (99.3% to 99.7%). Of the algorithms meant for external quality assessment, the PPVs varied widely and were often <50%, suggesting that these quality indicators detected many events that were not (CLA)BSI. Again, study designs with higher risks of bias tended to show higher accuracy.

Urinary tract infection

Fifteen studies investigated urinary tract infection (UTI), seven focusing specifically on catheter-associated UTI (CAUTI). In algorithms relying on administrative data to identify patients receiving a urinary catheter, the low sensitivity of CAUTI detection was striking (figure 3C,

Table 1 Main characteristics of included studies, stratified by targeted type of HAI

N studies (N comparisons)	Total 57 (71)	SSI 34 (44)	BSI 24 (29)	UTI 15 (15)	Pneumonia 14 (15)	Other 2 (2)
Device-associated	20	–	12	7	7	1
ICU only	5	1	3	2	3	0
Type of reference standard						
NHSN	35	26	9	6	7	2
(VA)SQIP	6	2	6	2	3	0
Clinical	4	1	3	1	1	0
Other	12	5	6	6	3	0
Application of administrative data						
External quality assessment	24	9	19*	6	8	0
Within hospital surveillance	18	13	3	7	4	1
Combined with other HAI indicators	15	12	3	2	2	1
Specific quality metric						
PSI	9	1	10	0	2	0
HAC	3	0	2	1	0	0
PHC4	4	4	3	3	4	0
Region of origin						
USA	44 (55)	22 (29)	19 (24)	10 (10)	9 (10)	1 (1)
Europe	8 (10)	8 (9)	4 (4)	4 (4)	4 (4)	1 (1)
Other	4 (6)	4 (6)	1 (1)	1 (1)	1 (1)	0 (0)
High risk of bias on QUADAS domain						
Patient selection	1 (1)	1 (1)	1 (1)	0 (0)	1 (1)	0 (0)
Index test	0 (3)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)
Reference standard	19 (27)	11 (18)	6 (7)	4 (4)	2 (2)	1 (1)
Flow	19 (29)	10 (18)	8 (11)	4 (4)	3 (4)	1 (1)
Verification pattern						
Complete or random sample	37 (42)	23 (26)	16 (18)	11 (11)	10 (10)	1 (1)
Complete with discrepant analysis	3 (6)	3 (6)	1 (2)	1 (1)	1 (2)	0 (0)
Partial, based on index test only	8 (8)	2 (4)	5 (7)	2 (2)	2 (2)	0 (0)
Partial, based on index and other tests	8 (12)	6 (6)	1 (1)	1 (1)	1 (1)	1 (1)
Other or unclear	1 (3)	0 (2)	1 (1)	0 (0)	0 (0)	0 (0)
Data availability						
Complete 2×2 table, by HAI type	29	20	10	6	6	1
Complete 2×2 table, HAI combined	3	3	2	4	3	0
Positive predictive value only, by HAI	9	3	6	1	2	0
Other	9	2	5	3	3	0
No data extraction possible	7	6	1	1	0	1

Some studies presented multiple comparisons and/or assessed more than 1 type of HAI; the number of comparisons is shown in brackets.
*One study targeting external quality assessment using administrative data combined with other sources of data.
BSI, bloodstream infections; HAC, Healthcare-associated condition as defined by the Centers for Medicare and Medicaid Services; HAI, healthcare-associated infections; ICU, intensive care unit; NHSN, National Healthcare Safety Network; PHC4, Pennsylvania Healthcare Cost Containment Counsel code selection; PSI, Patient Safety Indicator; QUADAS, Quality assessment for diagnostic accuracy studies; SSI, surgical site infection; UTI, urinary tract infection; (VA)SQIP, (Veteran's Administration) Surgical Quality Improvement Project.

see online supplementary S5C, S6).[78 76] Sensitivity was higher for UTI, but PPVs were universally below 25%, except in the study by *Heisler et al*; this study, however, additionally scrutinised flagged records for the presence of UTI.[34]

Pneumonia

Fourteen studies evaluated pneumonia, of which nine specifically targeted ventilator-associated pneumonia (VAP). The presence of mechanical ventilation was either determined within the administrative data algorithm[34 43] or by manual methods.[67] For VAP, sensitivity ranged from 35% to 72% and PPV from 12% to 57%. For pneumonia, sensitivity and PPV hovered around 40%, although the studies used very diverse methodologies (figure 3D, see online supplementary S5D).

Other HAI and aggregated estimates

One study assessed the value of administrative data for detection of postpartum endometritis (data extraction not possible) and one the occurrence of drain-related meningitis. In addition, six studies presented data aggregated for multiple types of HAI (figure 3E, see online supplementary S5E). Also, for these studies, sensitivity did not exceed 60%, with similar or lower PPVs.

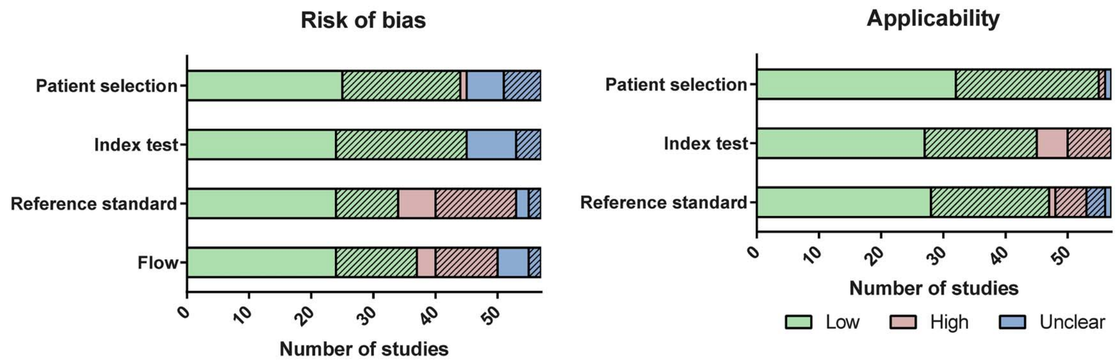

Figure 2 Summary of risk of bias and applicability for all studies (n=57), assessed using the *Quality Assessment for Diagnostic Accuracy Studies (QUADAS-2)* methods. Some studies contain multiple comparisons; in this case, the lowest risk of bias per study is included. Shading denotes studies where extraction of complete two-by-two tables was not possible, including studies only assessing positive predictive values.

Algorithms combining administrative data with clinical data

Fifteen studies in this review evaluated the accuracy of administrative data in an algorithm that also included other (automated) indicators of HAI for within-hospital surveillance. Eight allowed for extraction of accuracy estimates of administrative data alone (labelled as 'Int (C)' in figure 3) and only very few provided the data necessary to fairly assess the incremental benefit of administrative data over clinical data such as antimicrobial dispensing or microbiology results. In these studies, gains in sensitivity obtained by adding administrative data were at most 10 percent points (data not shown).[23 49 50 59 74 75]

DISCUSSION

In the light of the increasing attention for evaluating, improving and rewarding quality of care, efficient and reliable measures to detect HAI are vital. However, as demonstrated by this comprehensive systematic review, administrative data have limited—and very variable—accuracy for the detection of HAI. In addition, algorithms to identify infections related to invasive devices such as central lines and urinary catheters are particularly problematic. All included studies were very heterogeneous in specifications of both the administrative data algorithms and the reference standard. Thorough methodological quality assessment revealed that incomplete ascertainment of HAI status and/or lack of blinding of assessors occurred in one-third of studies, thus introducing a risk of bias and complicating a balanced interpretation of accuracy estimates. Studies employing designs associated with a higher risk of bias appeared to provide a more optimistic picture than those employing more robust methodologies.

The drawbacks of administrative data for the purpose of HAI surveillance have been emphasised previously, especially from the perspective of (external) interfacility comparisons.[3 9 11 79] In comparison with a recent systematic review that assessed the accuracy of administrative data for HAI surveillance,[9] we identified a larger number of primary studies (partly due to broader inclusion criteria) and distinguished between administrative data algorithms developed for different intended applications. This prior review suggests that despite their moderate sensitivity, administrative data may be useful within broader algorithmic (automated) routine surveillance; notably, the studies in our systematic review demonstrated only modest gains in efficiency over other automated methods.[23 25 26 32 63 67 74] Surprisingly, there was no clear difference between administrative data algorithms developed for the purpose of supporting within-hospital surveillance versus those meant for external quality assessment in terms of sensitivity or PPV. Sensitivity was highly variable and PPVs were modest at best, also in algorithms targeting very specific events (CAUTI, CLABSI) for external benchmarking or payment rules. Administrative data may, however, be advantageous when aiming to track HAIs that require postdischarge surveillance across multiple healthcare facilities or levels of care, such as SSI.[41 80] Importantly, a considerable number of studies were performed in the USA, with a specific billing and quality evaluation system; hence, some quality metrics and coding systems may not be applicable to other countries.

A number of previously published studies explored reasons for the inability of administrative data to detect HAI. For specific quality measures, differences in HAI definitions between the quality metrics and NHSN methods may account for a portion of the discordant cases,[81]; other explanations include the erroneous detection of infections present-on-admission (PoA) or infections not related to the targeted device, incorrect coding, insufficient clinician documentation, challenges in identifying invasive devices or the limited number of coding fields available.[53 69 44 51 76 82 83] The precarious balance between the accuracy of administrative data and their use in quality measurement and pay-for-performance programmes has been argued previously, especially as these efforts may encourage coding practices that further undermine the accuracy of

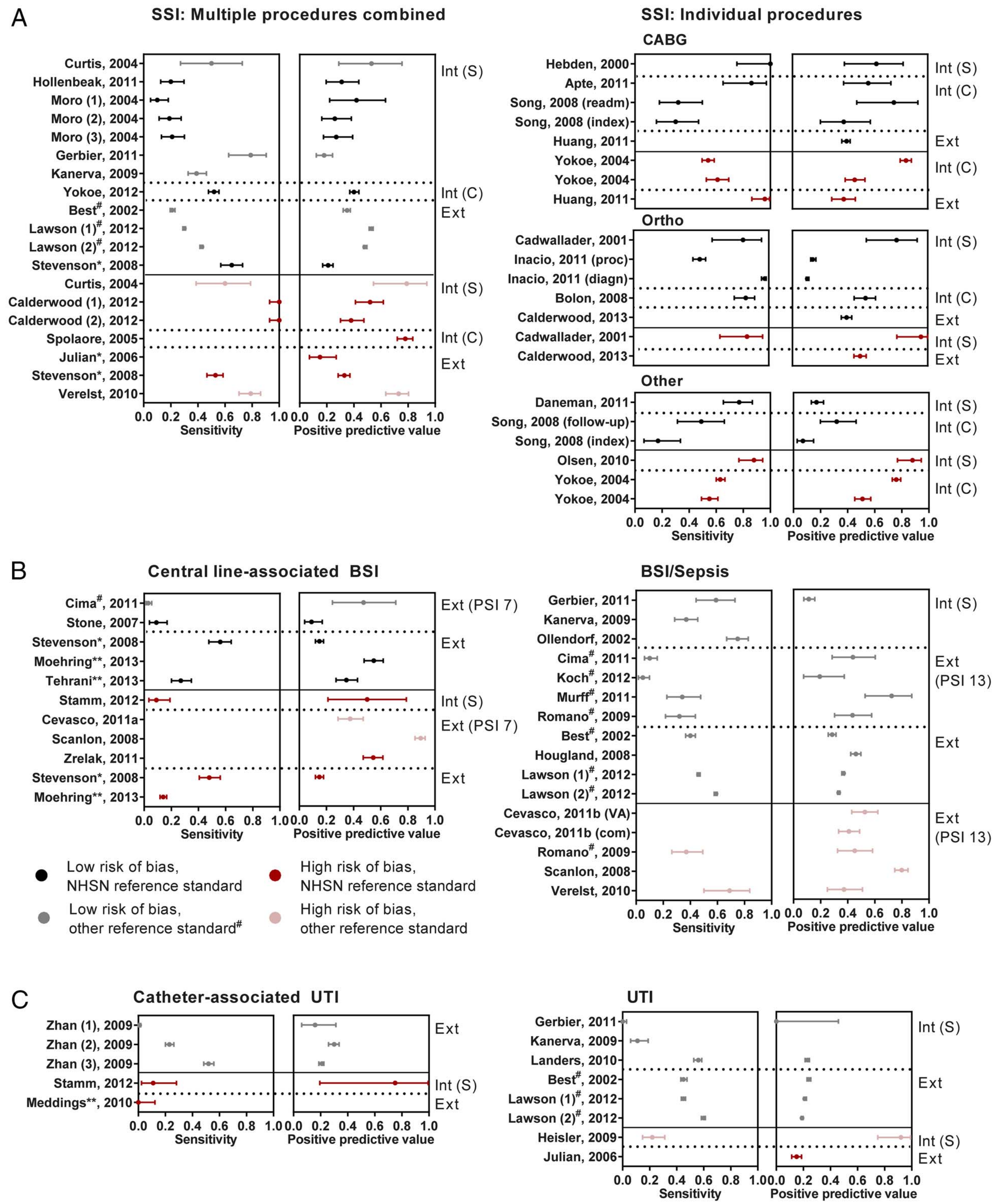

Figure 3 Forest plots for sensitivity and positive predictive value, stratified by HAI type and relevant study characteristics. Studies are grouped by the intended application of administrative data: Int (S)—used in isolation to support within-hospital surveillance efforts, Int (C)—used to support within-hospital surveillance, combined with other indicators of infection, Ext—used for external quality assessment, including public reporting and pay-for-performance. BSI, bloodstream infection; CABG, coronary artery bypass graft; DRM, drain-related meningitis; HAI, healthcare-associated infections; Ortho, orthopedic procedure; PSI, patient safety indicator; Sep, sepsis; SSI, surgical site infection; UTI, urinary tract infection. In studies including multiple specifications of the administrative data algorithm, these are numbered sequentially. 95% CIs are derived using the exact binomial method. If multiple study designs were performed within a single study, they are mentioned separately. #Reference standard from Surgical Quality Improvement Project (NSQIP or VASQIP). *Code selection based on specification from Pennsylvania Health Cost Containment Council. ** HAC specification.

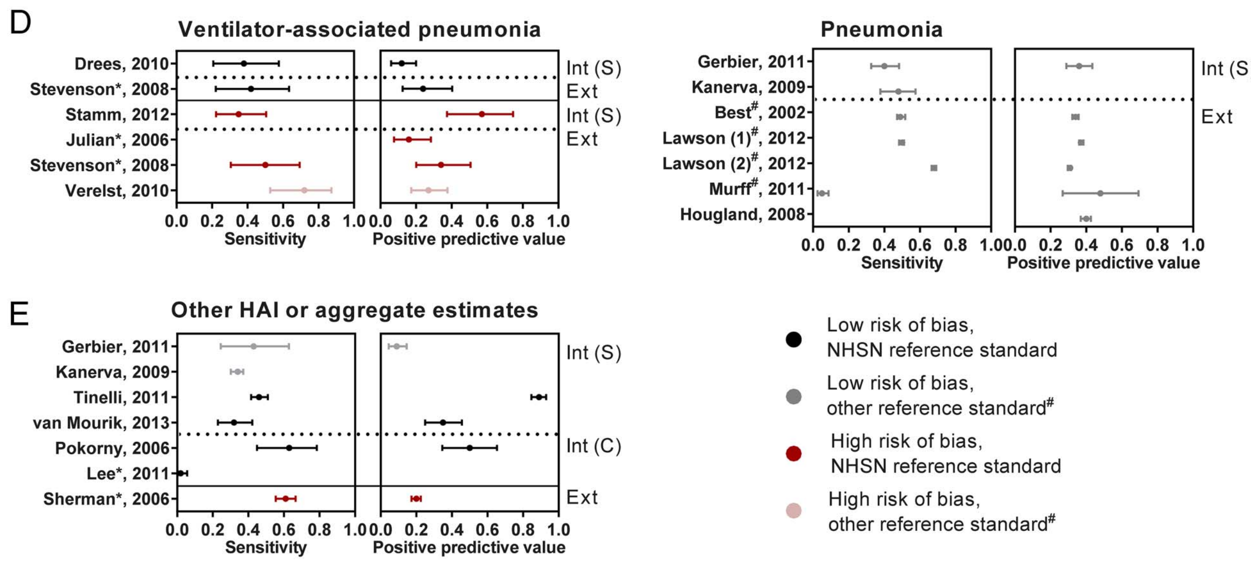

Figure 3 Continued.

administrative data.[11] Recent studies have provided mixed evidence regarding a change in coding practice in response to the introduction of financial disincentives or public reporting programmes.[84–86]

Several refinements in coding systems are currently in progress that may affect the future performance of administrative data. First, the transition to the 10th revision of the International Classification of Disease (ICD-10) may provide increased specificity due to the greater granularity of available codes.[87] Only seven studies in this review used the ICD-10, often in a setting that was not directly comparable to settings using the ICD-9 (mainly the USA), and some studies purposefully mapped the ICD-10 codes to mimic the ICD-9. Second, the number of coding fields available in (standardised) billing records has increased in recent years, allowing for more secondary diagnoses to be recorded; however, it is unclear whether expansion beyond 15 fields will benefit the HAI registration and other complications.[60 88] Third, the adoption and accuracy of PoA indicators in the process of code assignment remains to be validated, and they were incorporated in only a few studies included in this review.[78 89] Finally, this systematic review could not provide sufficient data to evaluate changes in coding accuracy since the US introduction of financial disincentives in 2008 for certain HACs that were not present on admission. Ongoing studies are needed to assess the impact of these changes in coding systems on their accuracy for HAI surveillance.

The frequent use of partial or differential verification patterns may be explained by the well-known limitations with quality of traditional surveillance as the reference standard in conjunction with the workload of applying manual surveillance to large numbers of patients.[23 25 26 32 63 67 74] Although reclassifying missed cases after a second review will result in more accurate detection of HAI, this differential application of the second review may bias the performance estimates upwards,[18] unless it is applied to (a random sample of) all cases, including concordant HAI-negative and HAI-positive cases.[23 67 90]

Despite efforts to identify all available studies, we cannot exclude the possibility of having missed studies and nor did we assess publication bias. In addition, as the search was closed in March 2013, a number of primary studies within the domain of this systematic review have been published since closure of the search. The findings of these studies were in line with our observations.[80 82 83 90–99] In addition, as a result of our broad inclusion criteria, the included studies were very diverse, complicating the interpretation of the results. Contrary to a previous systematic review,[9] the small number of comparable studies motivated us to refrain from generating pooled summary estimates in most cases. Future evaluations of the accuracy of administrative data should consider applying the same reference standard to all patients, or—if unfeasible—to a random sample in each subgroup of the two-by-two table and ensure blinding of assessors. To facilitate a balanced interpretation of the results, estimates of diagnostic accuracy calculated before and after reclassification should also be reported separately.[100]

CONCLUSION

Administrative data such as diagnosis and procedure codes have limited, and highly variable, accuracy for the surveillance of HAI. Sensitivity of HAI detection was insufficient in most studies and administrative data algorithms that target specific HAI for external quality reporting also had generally poor PPVs, with identification of device-associated infections being the most challenging. The relative paucity of studies with a robust methodology and the diverse nature of the studies, together with continuous refinements in coding systems, preclude reliable forecasting of the accuracy of administrative data in future applications. If administrative data continue to be used for the purposes of HAI surveillance, benchmarking or payment, improvement to existing algorithms and their robust validation is imperative.

Author affiliations
[1]Department of Medical Microbiology, University Medical Center Utrecht, Utrecht, The Netherlands
[2]Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Utrecht, The Netherlands
[3]Department of Population Medicine, Harvard Pilgrim Health Care Institute, Harvard Medical School, Boston, Massachusetts, USA
[4]Division of Infectious Diseases, Boston Children's Hospital, Boston, Massachusetts, USA

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Contributors MSMvM designed the study, performed the search, critically appraised studies, performed the analysis and drafted the manuscript; PJvD critically appraised studies and helped write the manuscript; MJMB and KGMM assisted in the study design, critical appraisal, data analysis and writing of the manuscript; GML assisted in the study design, data interpretation and writing of the manuscript.

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Supplementary data

"Accuracy of administrative data for surveillance of healthcare-associated infections: a systematic review"

Authors:

Maaike S.M. van Mourik, Pleun Joppe van Duijn, Karel G.M. Moons, Marc J.M. Bonten, Grace M. Lee

Contents:

S1. Search Strategy

Databases: Medline/Pubmed, EMBASE, CINAHL, Cochrane.
All searches in Titles + Abstract
Limits: Published between after 1995, Languages: English, Dutch, French, German
Search dates: Initial search march 8th 2012, search closure March 1st 2013.

Outcome: Healthcare associated infection	Search terms : *Infection, infections, hai, infectious, sepsis, meningitis, notifiable, SSI, VAP, pneumonia, CAUTI, CLABSI, CABSI, BSI*

AND

Determinant: administrative data	Search terms : *ICD, international Classification of Diseases, administrative, discharge diagnos*, registry, registries, electronic data, claim data, claims data, reimbursement, health plan data, healthplan, medicare, diagnostic coding, discharge coding, discharge code(s), diagnostic coding, diagnostic code(s), diagnosis code(s), diagnosis coding, procedure code(s), procedure coding*

S2. Data collection, quality assessment items and assumptions

General characteristics

Item	Options	Considerations & assumptions
Author, year of publication		
HAI studied	SSI/BSI/sepsis/ CLABSI/VAP /UTI/CAUTI/Other	More than 1 may apply Specify details
Systematic post-discharge surveillance?	Yes/No	Only code as yes if explicit aim of the study.
Location of study	Country	
Number of participating centers		
Start and stop of patient inclusion		
Validation of previously developed algorithm	Yes/No	E.g. previous study, PHC4, PSI, HAC
Validation sample within the study	Yes/No	
Purpose of administrative data	Billing/ benchmarking /demographic/ unclear	If U.S.: code as billing
Setting: Medicare, VA or HMO only?	Yes/No (specify)	
Healthcare setting	Primary care, Inpatient, Outpatient, ICU	More than 1 possible
Academic hospital	Yes/No/Mixed (if multicenter)	
Public reporting	Yes/Potentially/No	Was the measure developed/tested as a means of public reporting or external quality benchmarking (as opposed to an in-hospital screening algorithm)

Assessment of risk of bias (adapted from QUADAS-2)

PATIENT SELECTION			
1	Method of patient selection	Describe in-/exclusion criteria	
2	Consecutive or random sample of patients enrolled	Yes/no	Random sampling scored as yes
3	Case-control design avoided	Yes/No	
4	Inappropriate exclusions avoided?	Yes/No	Is the sample enrolled representative of the domain (e.g. no exclusion of high-risk patients?)
5	Risk of bias patient selection	Low/Unclear/High	If#2, #3 or #4 = no, consider risk of bias
6	Applicability patient selection	Low/Unclear/High	
INDEX TEST			
1	Describe index test	Coding system used? Codes assigned by? Procedure codes to detect HAI? PSI algorithm List codes used, duration of follow-up	ICD-9 or ICD-10 Coders, physicians, other, unclear (US: professional coders assumed) No if only used to identify patients at risk Version number Specify use of pre-defined methods (PHC4, PSI, CMS…).
2	Were other tests assessed	Yes/No, specify	
3	Was the administrative data intended as the sole method of surveillance	Yes/no	E.g. were results of administrative data intended to be combined with microbiology results?
4	Was interpretation done without knowledge of the reference standard?	Yes/no	Were codes assigned without knowledge of reference standard?
5	Pre-specified threshold	Yes/no	Was code selection determined in advance? If unspecified and only a very specific code is used, also code as yes (e.g. 998.5 for SSI)
6	Risk of bias index test	Low/Unclear/High	If #4 or #5 = No, consider risk of bias.
7	Applicability index test	Low/Unclear/High	If #3 = No, score as High
REFERENCE STANDARD			
1	Describe reference standard	Method: Definitions used: Applied by:	Describe NHSN/NNIS, (VA)SQIP, Clinical, Other IP, trained nurses, physicians, other abstractor

2	Is the reference standard likely to correctly classify the patient	Yes/No	
3	Was it interpreted without knowledge of the index test?	Yes/No	If only patients flagged by code are received reference standard and/or coding status was unblinded score as No
4	Risk of bias	Low/Unclear/High	If #3 = No, consider risk of bias
5	Applicability	Low/Unclear/High	
FLOW AND TIMING			
1	Describe patients who did not receive 1 of both tests or are not in 2x2 table		Draw flowchart
2	Did all patients receive the RS?	Yes/No	If only assessing patients with positive reference test, score as No
3	Did all patients receive the same RS?	Yes/No	If all the patients receiving RS do not receive the *same* RS score as No.
4	Were all patients included in the analysis?	Yes/No	
5	Could the patient flow have introduced bias and why?	Low/Unclear/High	If #2 or #3 = Yes, consider risk of bias. If a large or important portion of patients are excluded (e.g. due to missing data), consider risk of bias.
6	How were missing data handled?	Description	

Data extraction:

	HAI present	**HAI absent**	**Total**
Codes +	TP	FP	
Codes -	FN	TN	
Total			

If only outcome measures are reported:

Sensitivity		PPV	
Specificity		NPV	
LR-		LR+	
Kappa		Degree of certainty	High – med – low

General remarks:

- If multiple index tests and/or reference standards and/or patient flow schemes are used in the study, all are assessed separately for their risk of bias (multiple comparisons).
- Data were extracted for each comparison presented, and also separately if
    - Multiple types of HAI
    - Multiple comparisons for each HAI
    - If multiple specifications of administrative data

S3. Risk of bias individual studies, stratified in case of multiple comparisons

Abbreviations & Legend
HAI types: (CA)UTI – (catheter-associated) urinary tract infection, (CLA)BSI – central-line associated bloodstream infection, Pneu – pneumonia, SSI – surgical site infection, VAP – ventilator-associated pneumonia.
Country: AUS – Australia, B E – Belgium, CAN – Canada, DK – Denmark, ESP – Spain, FI – Finland, FR – France, IT-Italy, JP – Japan, NL – Netherlands, USA – United States of America,
Definition: CDC-NHSN or CDC-NNIS – definitions from the Centers for Disease Control Healthcare Safety Network or its predecessor, (VA/N)SQIP – definitions & methods from the National (or Veteran's Affairs) Surgical Quality Improvement Project.
Intend appl: Intended application of administrative data within HAI surveillance.
Ext – for external quality assessment, e.g. public reporting or pay-for-performance.
Int (S) – to support within hospital surveillance as sole method of finding possible HAI cases.
Int (C) – to support within hospital surveillance, combined with other indicators of HAI.
If applicable, specific metrics are indicated: HAC – Healthcare-associated condition as defined by the Centers for Medicare and Medicaid Services, PHC4 – code selection specified by the Pennsylvania Healthcare Cost Containment Council, PSI – Patient Safety Indicator.
N : design number
Risk of bias (Rob) & applicability domains: Patient selection (Pat Sel), Index test, Reference standard (Ref) and Flow. If a study assesses only the positive predictive value (partial verification, fully dependent on the index test – e.g. administrative data), and the risk of bias of the on the flow domain is low for the PPV estimate, these studies have been marked as "PPV" in the risk of bias on flow column. The overall risk of bias of the PPV estimate is marked in RoB PPV column.
Notes:
The following studies used the ICD-10 coding system: Curtis 2004, Daneman 2011, Gerbier 2011, Kanerva 2009, Lee 2011, Leth 2006, Leth 2010. Heisler 2009 used a different coding system.
In the following studies a present-on-admission indicator was explicitly included in the administrative data algorithm:
Cima 2011, Haley 2012, Koch 2012, Meddings 2010, Moehring 2013, Murff 2011, Tehrani 2013, Zrelak 2011

Author & year	HAI studied	Country	N Centers	Study period	definition	Intend appl	N	Risk of bias				Applicability			RoB PPV
								Pat sel	Index test	Ref	Flow	Pat sel	Index test	Ref	
Apte, 2011	SSI,	USA	1	2007	Unclear	Int (C)	2	Low	Low	High	Low	Low	Low	High	High
Apte, 2011	SSI,	USA	1		CDC NHSN	Int (C)		Low	Low	Low	Uncl	Low	Low	Low	Uncl
Best, 2002	SSI, Sepsis, Pneu, UTI,	USA	123	1994 - 1995	(VA/N)SQIP	Ext	1	Uncl	Low	Low	Low	Low	Low	Low	Uncl
Bolon, 2009	SSI,	USA	8	2002 - 2005	CDC NHSN	Int (C)	1	Low	Low	Uncl	Low	Low	High	Low	Low
Braun, 2006	BSI,	USA	28	1999	Clinical	Ext*	1	Uncl	Low	High	High	Low	Low	High	High
Cadwallader, 2001	SSI,	AUS	1	1998 - 1999	CDC NNIS	Int (S)	2	Low	Low	Low	Low	Low	Low	Low	Low
Cadwallader, 2001	SSI,	AUS	1		CDC NNIS	Int (S)		Low	Low	High	High	Low	Low	Low	High
Calderwood, 2012	SSI,	USA	4	2007	CDC NHSN	Int (S)	1	Uncl	Uncl	High	High	Low	Low	Low	High
Calderwood, 2013	SSI,	USA	3296	2005 - 2007	CDC NHSN	Ext	2	Low	Low	High	PPV	Low	Low	Low	High
Calderwood, 2013	SSI,	USA	3296		CDC NHSN	Ext		Low	High	High	PPV	Low	Low	Low	High
Campbell, 2011	SSI, UTI,	USA	1	2008	Other	Int (S)	1	Uncl	Uncl	Low	Low	Low	Low	High	Uncl
Cevasco, 2011a	CLABSI,	USA	28	2002 - 2007	Other	Ext PSI 3.1	1	Low	Low	High	PPV	Low	Low	Low	High
Cevasco, 2011b	Sepsis,	USA	75	2003 - 2007	Other	Ext PSI 3.1	2	Low	Low	High	PPV	Low	Low	Low	High
Cevasco, 2011b	Sepsis,	USA	75		Unclear	Ext PSI 3.1		Low	Low	High	PPV	Low	Low	Low	High
Cima, 2011	CLABSI, Sepsis,	USA	1	2006 - 2009	(VA/N)SQIP	Ext PSI 3.1	1	Low	Low	Low	Low	Low	Low	Low	Low
Curtis, 2004	SSI,	AUS	1	2001 - 2002	Other	Int (S)	2	Low	Low	Low	Low	Low	Low	Low	Low
Curtis, 2004	SSI,	AUS	1		Other	Int (S)		Low	Low	Uncl	High	Low	Low	Low	High
Daneman, 2011	SSI,	CAN	1	2008 - 2009	CDC NHSN	Int (S)	1	Uncl	Low	Low	Low	Low	Low	Low	Uncl
Drees, 2010	VAP,	USA	1	2007 - 2008	CDC NHSN	Int (S)	1	Low	Low	Low	Uncl	Low	Low	Low	Low
Gerbier, 2011	SSI, BSI, CLABSI, UTI, Pneu,	FR	1	2000 - 2007	Other	Int (S)	1	Low	Low	Low	Uncl	Low	Low	Low	Low
Haley, 2012	SSI,	USA	176	2008 - 2010	CDC NHSN	Ext	2	Low	Uncl	Low	Low	Low	Low	Low	Low
Haley, 2012	SSI,	USA	176		CDC NHSN	Ext		Low	Uncl	High	High	Low	Low	Low	High
Hebden, 2000	SSI,	USA	1	1997	CDC NNIS	Int (S)	1	Low	Low	Low	Low	Low	Low	Low	Low
Heisler, 2009	UTI, CAUTI,	USA	1	2004 - 2005	Clinical	Int (S)	1	Low	Low	High	Uncl	Low	Low	Uncl	High
Hollenbeak, 2011	SSI,	USA	1	2007 - 2008	CDC NHSN	Int (S)	1	Low	Low	Low	Low	Low	Low	Low	Low
Hougland, 2008	BSI, Pneu	USA	77	2001 - 2003	Unclear	Ext	1	Low	Low	Low	Uncl	Low	Low	Uncl	Low

Author & year	HAI studied	Country	N Centers	Study period	definition	Intend appl	N	Risk of bias				Applicability			RoB PPV
								Pat sel	Index test	Ref	Flow	Pat sel	Index test	Ref	
Huang, 2011	SSI,	USA	671	2005	CDC NHSN	Ext	3	Low	High	High	High	Low	Low	Low	High
Huang, 2011	SSI,	USA	671		Unclear	Ext		Low	Low	High	Uncl	Low	Low	High	High
Huang, 2011	SSI,	USA	671		CDC NHSN	Ext		Low	Low	High	High	Low	Low	Low	High
Inacio, 2011	SSI,	USA	?	2006 - 2008	CDC NHSN	Int (S)	1	Low	Low	Low	Low	Low	Low	Low	Low
Julian, 2006	SSI, VAP, UTI, CAUTI,	USA	1	2004	CDC NHSN	Ext PHC4	1	Low	Low	High	High	Low	Low	Low	High
Kanerva, 2009	SSI, BSI, UTI, Pneu,	FI	20	2005	Other	Int (S)	1	Low	Uncl	Low	Low	Low	Low	Low	Uncl
Koch, 2012	Sepsis,	USA	1	2009 - 2010	(VA/N)SQIP	Ext PSI 4.2	2	Low	Low	Low	Low	Low	Low	Low	Low
Koch, 2012	Sepsis,	USA	1		Other	Ext PSI 4.2		Low	Low	Low	Low	Low	Low	Low	Low
Landers, 2010	UTI,	USA	1	2007	Other	Int (S)	1	Low	Low	Low	Low	Low	Low	High	Low
Lawson, 2012	SSI, Sepsis, Pneu, UTI,	USA	214	2005 - 2008	(VA/N)SQIP	Ext	1	Low	Uncl	Low	Low	Low	Low	Low	Uncl
Lee, 2011	SSI, BSI, Pneu, UTI,	JP	4	2005 - 2009	CDC NHSN	Int (C) PHC4	1	Low	Low	Low	Low	High	High	Low	Low
Leth, 2006	SSI,	DK	1	1999 - 2002	CDC NHSN	Int (C)	2	Low	Uncl	Low	Low	Low	High	Low	Low
Leth, 2006	SSI,	DK	1	1999 - 2002	CDC NHSN	Int (C)		Uncl	Low	Uncl	Low	Low	Low	Low	Uncl
Leth, 2010	SSI	DK	3	2007 - 2008	CDC NHSN	Int (C)	1	Low	Low	Low	High	Low	High	Low	High
Meddings, 2010	CAUTI,	USA	1	2006 - 2007	Other	Ext HAC	1	Low	Low	High	High	Low	Low	High	High
Miner, 2004	SSI,	USA	7	1996 - 1999	CDC NNIS	Int (C)	1	Low	Low	High	High	Low	High	Low	High
Moehring, 2013	CLABSI,	USA	3	2007 - 2009	CDC NHSN	Ext HAC	1	Low	Low	Low	High	Low	Low	Low	Low
Moro, 2004	SSI,	IT	31	2001	CDC NNIS	Int (S)	1	Low	Uncl	Low	Low	Low	Low	Low	Uncl
Murff, 2011	Sepsis, Pneu	USA	6	1999 - 2006	(VA/N)SQIP	Ext PSI 3.1	1	Low	Low	Low	Low	Low	Low	Low	Low
Ollendorf, 2002	Sepsis,	USA	10	Uncl	Clinical	Int (S)	1	Uncl	Uncl	Low	Low	Uncl	Low	High	Uncl
Olsen, 2010	SSI,	USA	1	1998 - 2002	CDC NHSN	Int (S)	1	Uncl	Low	High	High	Low	Low	Low	High
Platt, 2002	SSI,	USA	4	1996 - 1999	CDC NNIS	Int (C)	1	Uncl	Low	High	High	Low	High	Low	High
Pokorny, 2006	CLABSI, VAP, CAUTI,	ESP	1	1999 - 2002	CDC NHSN	Int (C)	1	Low	Uncl	Low	Low	Low	High	Uncl	Uncl
Romano, 2009	Sepsis,	USA	110	2000 - 2001	(VA/N)SQIP	Ext PSI 2.1	2	Low	Low	Low	Low	Low	Low	Low	Low
Romano, 2009	Sepsis,	USA	110	2000 - 2001	(VA/N)SQIP	Ext PSI 2.1		Low	High	Low	Low	Low	Low	Low	High
Sands, 2003	SSI,	USA	5	1995 - 1997	CDC NNIS	Int (C)	1	Uncl	Low	High	High	Low	High	Low	High

Author & year	HAI studied	Country	N Centers	Study period	definition	Intend appl	N	Risk of bias				Applicability			RoB PPV
								Pat sel	Index test	Ref	Flow	Pat sel	Index test	Ref	
Scanlon, 2008	CLABSI, Sepsis,	USA	28	2003 - 2005	Other	Ext PDI	1	Low	Low	High	PPV	Low	Low	High	High
Sherman, 2006	SSI, CLABSI, VAP, CAUTI,	USA	1	2004	CDC NHSN	Ext PHC4	1	Low	Low	High	High	Low	Low	Low	High
Song, 2008	SSI,	USA	1	2005	CDC NNIS	Int (C)	1	Low	Uncl	Low	Low	Low	High	Low	Uncl
Spolaore, 2005	SSI,	IT	3	2001	CDC NHSN	Int (C)	1	Low	Low	High	PPV	Low	High	Low	High
Stamm, 2012	CLABSI, VAP, CAUTI,	USA	1	2009	CDC NHSN	Int (S)	1	Low	Uncl	Uncl	High	Low	Low	Low	High
Stevenson, 2008	SSI, CLABSI, VAP,	USA	1	2005	CDC NHSN	Ext PHC4	2	Low	Low	Low	Low	Low	Low	Low	Low
Stevenson, 2008	SSI, CLABSI, VAP,	USA	1	2005	CDC NHSN	Ext PHC4		Low	Low	Uncl	High	Low	Low	Low	High
Stone, 2007	CLABSI,	USA	24	2002	CDC NHSN	Ext PSI 2.1	1	Low	Low	Low	Low	Low	Low	Low	Low
Tehrani, 2013	CLABSI,	USA	6	2009 - 2011	CDC NHSN	Ext HAC	2	Low	Low	Low	Low	Low	Low	Low	Low
Tehrani, 2013	CLABSI,	USA	6	2009 - 2011	CDC NHSN	Ext HAC		Low	Low	Uncl	PPV	Low	Low	Low	Low
Tinelli, 2011	SSI, UTI,	USA	28	2005 - 2006	CDC NHSN	Int (S)	1	Low	Uncl	Low	Low	Low	Low	Low	Uncl
van Mourik, 2013	Drain-related meningitis	NL	1	2004 - 2010	CDC NHSN	Int (S)	1	Uncl	Low	Low	Low	Low	Low	Low	Uncl
Verelst, 2010	SSI, Sepsis, VAP,	BE	8	2005	Clinical	Ext PSI 3.1	1	High	Low	Low	Uncl	Low	Low	Low	High
Yokoe, 2001	Postpartum	USA	1	1993 - 1995	CDC NNIS	Int (C)	1	Low	Low	High	High	Low	High	Low	High
Yokoe, 2004	SSI,	USA	13	1998 - 2001	CDC NNIS	Int (C)	2	Low	Low	High	High	Low	High	Low	High
Yokoe, 2004	SSI,	USA	13	1998 - 2001	CDC NNIS	Int (C)		Low	Low	High	Uncl	Low	High	Low	High
Yokoe, 2012	SSI,	USA	5	2003 - 2005	CDC NHSN	Int (C)	1	Low	Low	Uncl	Low	Low	High	Low	Low
Zhan, 2009	CAUTI,	USA	uncl	2005 - 2006	Other	Ext	1	Uncl	Uncl	Low	Low	Low	Low	Uncl	Uncl
Zrelak, 2011	CLABSI,	USA	23	2005	CDC NHSN	Ext PSI 3.1	1	Low	Low	High	PPV	Low	Low	Low	High

S4. Summary risk of bias, by HAI type.

Risk of bias was assessed using the *Quality Assessment for Diagnostic Accuracy Studies (QUADAS-2)* methods. Some studies contain multiple comparisons; in this case the lowest risk of bias per study is included. Shading denotes studies where extraction of complete two-by-two tables was not possible, including studies only assessing positive predictive values.

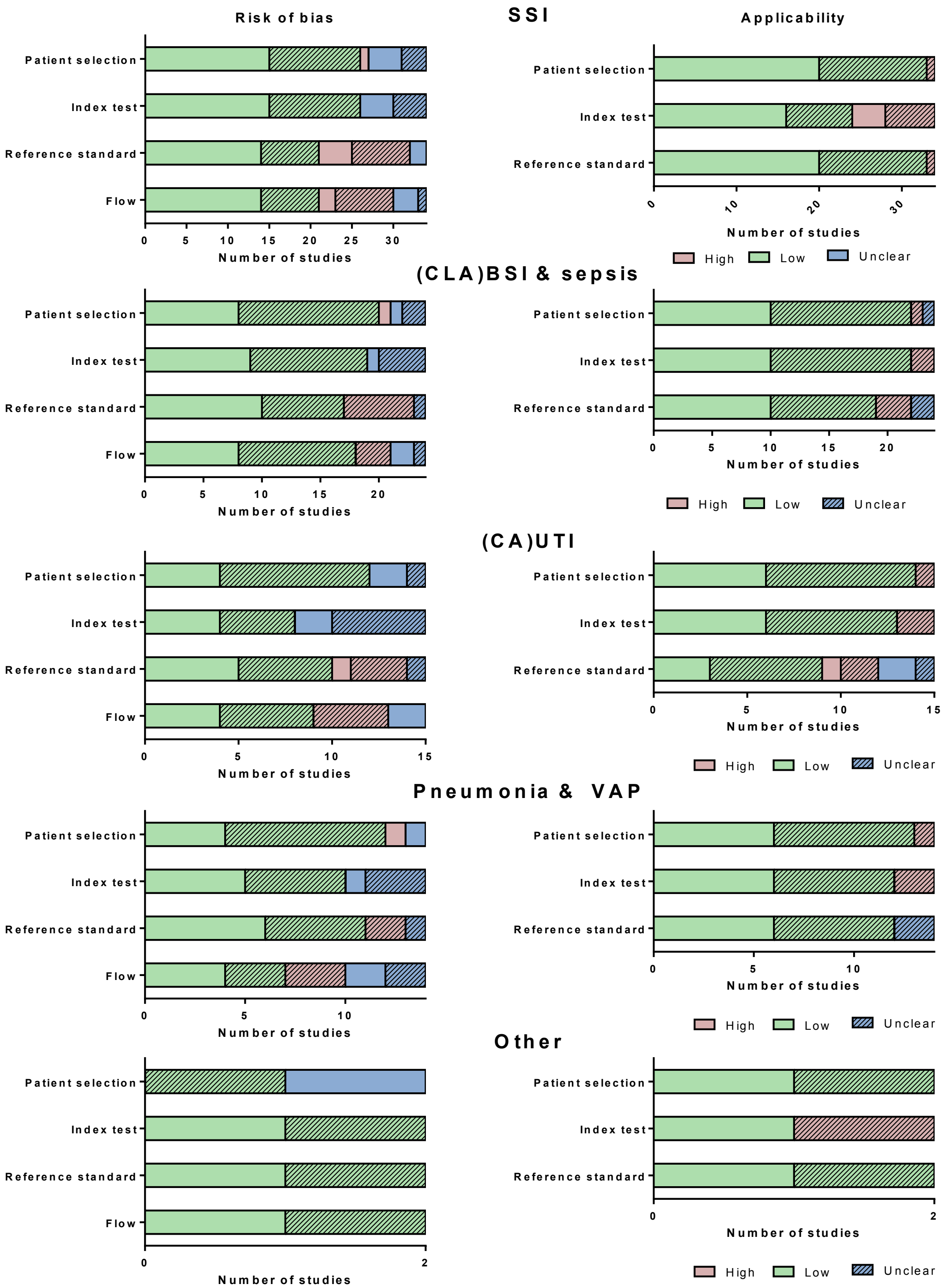
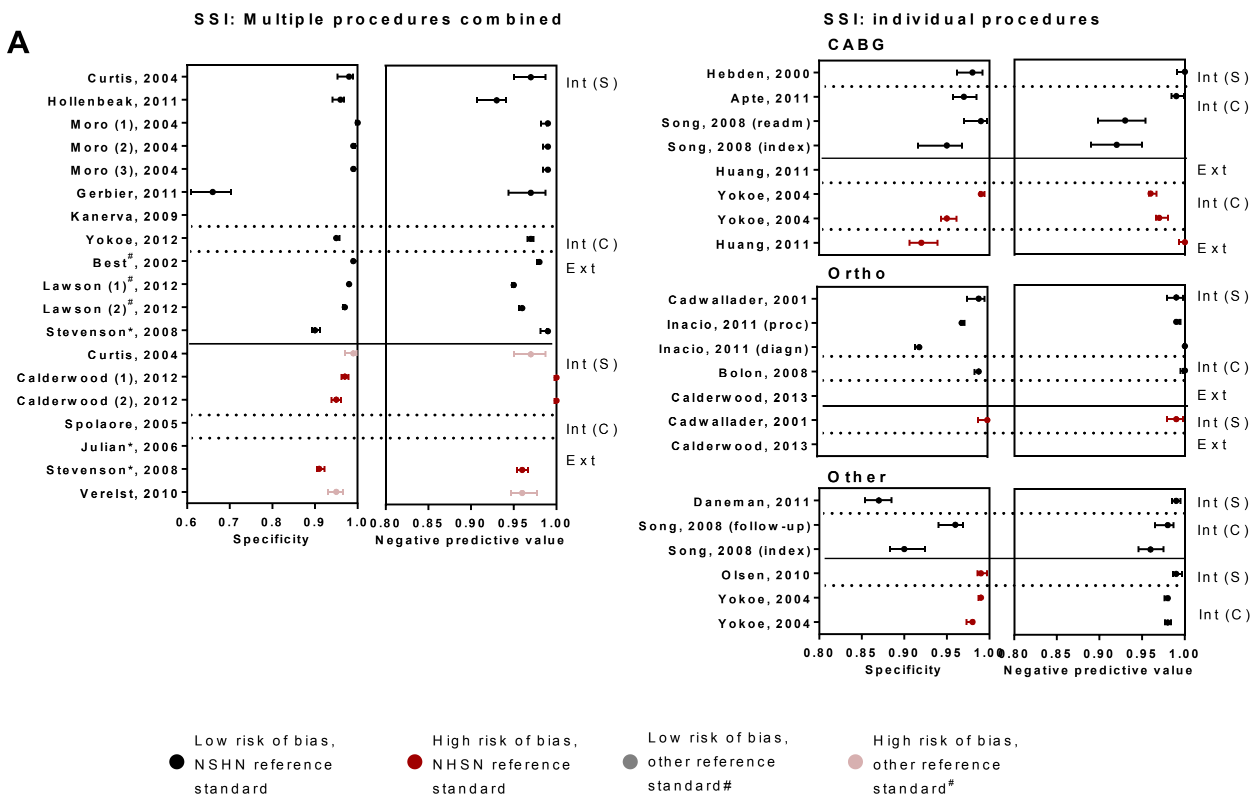


Figure S5. Forest plots for specificity and negative predictive value, stratified by HAI type and relevant study characteristics.

Studies are grouped by the intended application of administrative data:
Int (S) – used in isolation to support within-hospital surveillance efforts,
Int (C) – used to support within-hospital surveillance, combined with other indicators of infection,
Ext – for external quality assessment, including public reporting and pay-for-performance.
In studies including multiple specifications of the administrative data algorithm, these are numbered sequentially. 95% confidence intervals are derived using the exact binomial method.

Abbreviations: BSI – bloodstream infection, CABG – coronary artery bypass graft, DRM – drain-related meningitis, Ortho – orthopedic Procedure, PSI – Patient safety indicator, Sep – Sepsis, SSI – surgical site infection, UTI – urinary tract infection.
#: reference standard from Surgical Quality ImProvement Project (NSQIP or VASQIP). *: Code selection based on specification from Pennsylvania Health Cost Containment Council. **: HAC specification.

A. Surgical site infection, B. (Catheter-associated) bloodstream infection, C. (Ca
theter-associated) urinary tract infection, D. (Ventilator-associated) pneumonia. E. Other HAI or studies Extesenting only data aggregated for multiple types of infection.



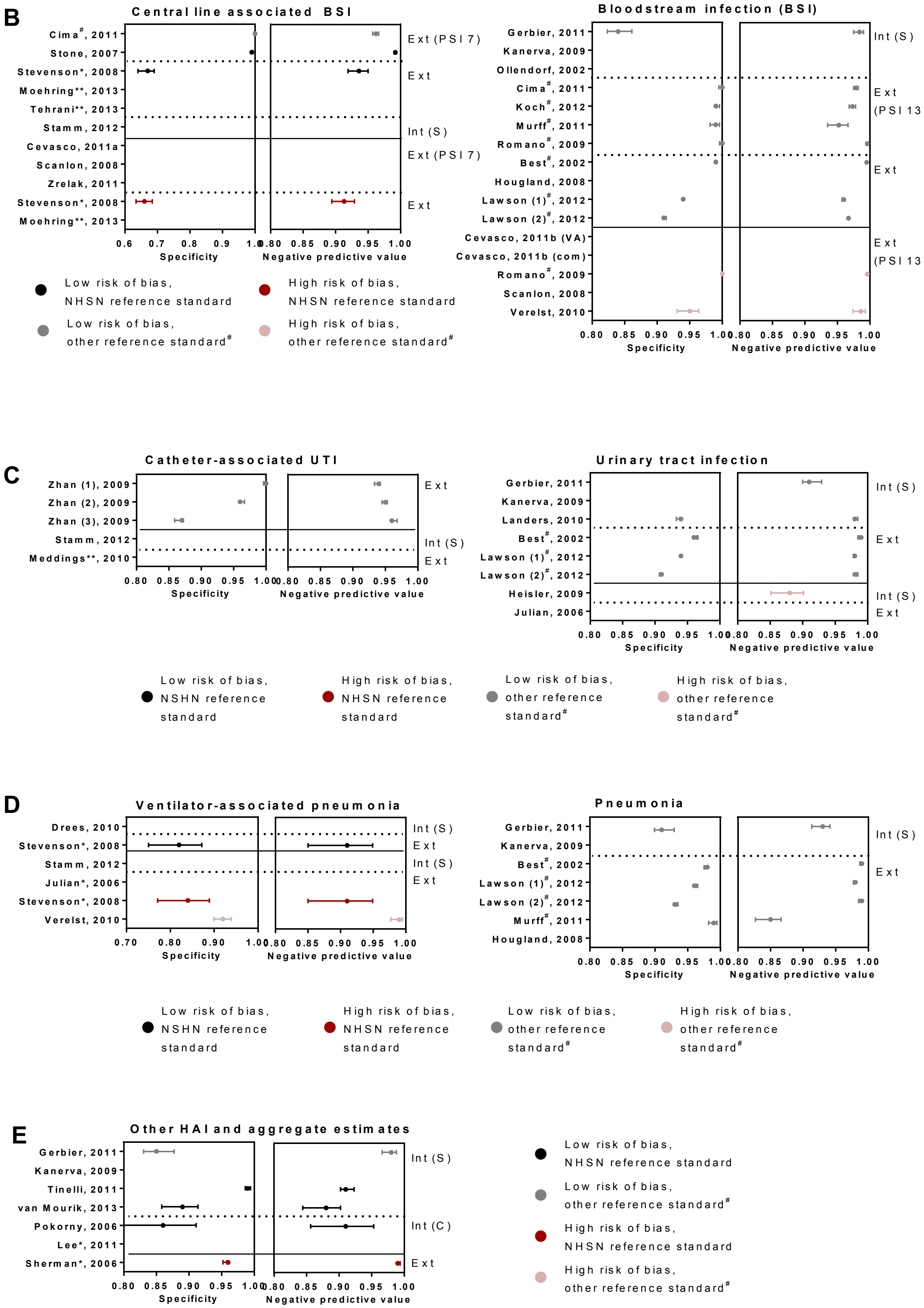

B
Central line associated BSI
Cima#, 2011
Stone, 2007
Stevenson*, 2008
Moehring**, 2013
Tehrani**, 2013
Stamm, 2012
Cevasco, 2011a
Scanlon, 2008
Zrelak, 2011
Stevenson*, 2008
Moehring**, 2013
Ext (PSI 7)
Ext
Int (S)
Ext (PSI 7)
Ext
0.6 0.7 0.8 0.9 1.0
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Low risk of bias, NHSN reference standard
High risk of bias, NHSN reference standard
Low risk of bias, other reference standard#
High risk of bias, other reference standard#
Bloodstream infection (BSI)
Gerbier, 2011
Kanerva, 2009
Ollendorf, 2002
Cima#, 2011
Koch#, 2012
Murff#, 2011
Romano#, 2009
Best#, 2002
Hougland, 2008
Lawson (1)#, 2012
Lawson (2)#, 2012
Cevasco, 2011b (VA)
Cevasco, 2011b (com)
Romano#, 2009
Scanlon, 2008
Verelst, 2010
Int (S)
Ext (PSI 13)
Ext
Ext (PSI 13)
0.80 0.85 0.90 0.95 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
C
Catheter-associated UTI
Zhan (1), 2009
Zhan (2), 2009
Zhan (3), 2009
Stamm, 2012
Meddings**, 2010
Ext
Int (S)
Ext
0.80 0.85 0.90 0.95 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Urinary tract infection
Gerbier, 2011
Kanerva, 2009
Landers, 2010
Best#, 2002
Lawson (1)#, 2012
Lawson (2)#, 2012
Heisler, 2009
Julian, 2006
Int (S)
Ext
Int (S)
Ext
0.80 0.85 0.90 0.95 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Low risk of bias, NSHN reference standard
High risk of bias, NHSN reference standard
Low risk of bias, other reference standard#
High risk of bias, other reference standard#
D
Ventilator-associated pneumonia
Drees, 2010
Stevenson*, 2008
Stamm, 2012
Julian*, 2006
Stevenson*, 2008
Verelst, 2010
Int (S)
Ext
Int (S)
Ext
0.70 0.80 0.90 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Pneumonia
Gerbier, 2011
Kanerva, 2009
Best#, 2002
Lawson (1)#, 2012
Lawson (2)#, 2012
Murff#, 2011
Hougland, 2008
Int (S)
Ext
0.80 0.85 0.90 0.95 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Low risk of bias, NSHN reference standard
High risk of bias, NHSN reference standard
Low risk of bias, other reference standard#
High risk of bias, other reference standard#
E
Other HAI and aggregate estimates
Gerbier, 2011
Kanerva, 2009
Tinelli, 2011
van Mourik, 2013
Pokorny, 2006
Lee*, 2011
Sherman*, 2006
Int (S)
Int (C)
Ext
0.80 0.85 0.90 0.95 1.00
Specificity
0.80 0.85 0.90 0.95 1.00
Negative predictive value
Low risk of bias, NHSN reference standard
Low risk of bias, other reference standard#
High risk of bias, NHSN reference standard
High risk of bias, other reference standard#

Table S6: Administrative data algorithm, by HAI type

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

SSI – CABG

Study	Codes used (Inpatient only, primary & secondary codes unless specified)	Duration of follow-up	Includes readmissions	Purpose of algorithm
Apte 2011	ICD-9: 998.5,998.51, 998.59	30d	Yes	Internal, comb
Hebden 2000	ICD-9 : 998.59	Unclear	Unclear	Internal, sole
Huang 2011	ICD-9: 34.01 34.02 34.10 86.01 86.04 86.09 86.22 86.28 91.71 91.72 91.73 513.1 519.2 682.2 682.3 682.8 686.8 686.9 730.00 730.08 730.09 730.20 730.28 730.29 730.30 730.38 730.39 730.80 730.88 730.39 730.90 730.98 730.99 785.52 790.7 875.0 879.8 879.9 891.0 891.1 996.60 996.61 99.62 996.71 998.31 998.32 998.51 998.83 998.9 CPT: 10060 10061 10140 10160 10180 11010 11040 11041 11042 11043 11044 12020 12021 13160 50000 50005 39000 39010; The algorithm was refined after piloting; unclear which codes are included in further analyses. Includes outpatient codes	60d	Yes	External
Platt 2002†	ICD-9: 998.0, 998.3, 998.5, 998.51, 998.59, 998.83, 780.6, 891.0, 891.1, 682.6, 682.9, 998.9 , 38.0 , 38.1, 38.10, 38.11, 38.19, 38.2, 38.3, 38.4, 38.40, 38.41, 38.42, 38.43, 38.44, 38.49, 38.8, 38.9, 790.7, 611.0, 682.0, 682.1, 682.2, 682.3, 682.4, 682.5, 682.6, 682.7, 682.8, 682.9, 686.0, 686.1, 686.8, 686.9, 958.3, 711.00, 996.6, 996.60, 996.61, 996.62, 996.63, 996.64, 996.65, 996.66, 996.67, 996.68, 996.69, 674.3, 879.0, 879.1, 879.2, 879.3, 879.4, 879.5, 879.6, 879.7, 879.8, 879.9, 875.0, 875.1 (also in outpatient setting). CPT: 87040, 87072, 87075, 87076, 87081, 87082, 87083, 87084, 10180, 11000, 11001, 15852 Note: the codes are included in a multivariable algorithm	30d	Yes	Internal, comb
Sands 2003†	Similar (or identical to Platt 2002)	30d	Yes	Internal, comb
Song 2008	ICD-9: 998.51, 998.59, 875.1, 519.2, 780.6	60d	Yes	Internal, comb
Yokoe 2004	ICD-9: 998.5, 998.51, 998.50	60d	Yes	Internal, comb

Abbreviations: CABG – coronary artery bypass graft, SSI – surgical site infection

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

SSI-Orthopedic

Study	Codes used (Inpatient only, primary & secondary unless specified)	Duration of follow-up	Includes readm	Purpose of algorithm
Bolon 2009	ICD-9: 998.5, 998.51, 998.51, 998.59, 996.66	365d	Yes	Internal, comb
Cadwallader, 2001	ICD-9: 996.66, 998.5, E878.1	30/365d	Yes	Internal, sole
Calderwood 2013	*THA:* ICD-9 Procedures: 84.56, 86.01, 86.22, 86.28 ICD-9: 686.8, 686.9, 711.00, 711.05, 711.08, 711.09, 711.40, 711.45, 711.48, 711.49, 711.90, 711.95, 711.98, 711.99, 730.00, 730.05, 730.08, 730.09, 730.10, 730.15, 730.18, 730.19, 730.20, 730.25, 730.28, 730.29, 730.90, 730.95, 730.98, 730.99, 996.60, 996.66, 996.67, 996.69, 998.5, 998.51, 998.59, 998.6 CPT: 10140, 10160, 10180, 12021, 13160, 20000, 20005, 26990, 26991, 26992, 27030, 27070, 27090, 27091, 27122, 27301, 27303, 35860 (includes outpatient)	365d	Yes	External
Inacio 2011	*1-120 day timeframe (wound only):* ICD-9: 998.30, 998.31, 998.32, 998.50, 998.51, 998.59, 680.5, 680.6, 680.9, 682.5, 682.6, 682.9, 686.9 *1-400 day timeframe (deep)* ICD 9: 711, 711.0, 711.00, 711.05, 711.06, 711.09, 711.60, 711.65, 711.66, 711.69, 711.90, 711.95, 711.96, 711.99, 730.00, 730.05, 730.06, 730.09, 730.20, 730.25, 730.26, 730.29, 730.90, 730.95, 730.96, 730.99, 996.6, 996.60, 996.66, 996.67, 999.3 ICD-9 Procedure: 80.00, 80.05, 80.06, 80.10, 80.16, 80.15, 78.60, 78.65, 78.66, 78.67, 78.69, 81.91, 86.04 (includes outpatient)	120d for superficial (wound) SSI 400d for deep SSI	Yes	Internal, sole

Abbreviations: SSI – surgical site infections, THA – total hip arthroplasty

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

SSI-other

Study	Target Procedure	Codes used (Inpatient only, primary & secondary unless specified)	Duration of follow-up	Includes readm	Purpose of algorithm
Campbell 2011†	Spinal surgery	Requested from corresponding authors; not available	LoS	No	Internal, sole
Daneman 2011	Caesarean section	ICD-10: O85002, O86002, O86004, O86009, O90202, K630, K750, L0331, L0332, L0333, N151, N730, K658, K650, O85004, N719, O86804, T813, T814, T857, T86842, T86822, T86882 (includes outpatient)	30	Yes	Internal, sole
Leth 2010†	Caesarean section	ICD-10: T81.4, O86.0 (incl. outpatient) Procedures: KLWB00, KMWB00, KLWC01, KMWC00, KMWC01	30	Yes	Internal, comb
Miner 2004†	Breast, caesarean section	*Caesarean section* ICD-9: 038 038.0 038.1 038.10 038.11 038.19 038.3 038.4 038.40 038.42 038.43 038.44 038.49 038.8 038.9 040.0 040.8 040.82 040.89 041 041.0 041.00 041.01 041.03 041.04 041.05 041.09 041.1 041.10 041.11 041.19 041.3 041.4 041.6 041.7 041.8 041.82 041.83 041.84 041.85 041.89 041.9 614.0 614.2 614.3 614.5 614.9 615 615.0 615.9 670 670.0 670.00 670.02 670.04 672 672.0 672.00 672.02 672.04 673.3 673.30 673.31 673.32 673.33, 673.34 682 682.2 682.5 686 686.8 686.9 780.6 790.7 996.6 996.60 996.62 996.69 998.5 998.51 998.59 Procedure: 86.01 86.04 86.22 10060 10061 10160 10180 11000 11001 *Breast* ICD-9: 675 675.0 675.00 675.01 675.02 675.03 675.04 675.1 675.10 675.11 675.12 675.13 675.14 675.2 675.20 675.21 675.22 675.23 675.24 675.8 (includes outpatient)	30/60	Yes	Internal, comb
Olsen 2010	Breast	ICD-9: 998.5, 998.51, 998.59, 996.69, 611.0, 682.2, 682.3 (in- and outpatient surgical care)	180	Yes	Internal, sole

Abbreviations: LoS – length of stay, SSI – surgical site infection

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

SSI – all/combined

Study	Procedure	Codes used (Inpatient only, primary & secondary unless specified)	Duration follow-up	Includes readm	Purpose of algorithm
Best 2002	All	ICD-9: 998.5	LoS	No	External
Calderwood, 2012	TKA, THA, Vascular surgery	**Limited list:** *TKA/THA:* ICD-9: 998.5, 998.51, 998.51, 998.59, 996.66 *Vascular:* ICD-9: 998.5, 998.51, 996.62 **Expanded list:** *THA:* Procedures: 84.56, 86.01, 86.22, 86.28 ICD-9: 686.8, 686.9, 711.00, 711.05, 711.08, 711.09, 711.40, 711.45, 711.48, 711.49, 711.90, 711.95, 711.98, 711.99, 730.00, 730.05, 730.08, 730.09, 730.10, 730.15, 730.18, 730.19, 730.20, 730.25, 730.28, 730.29, 730.90, 730.95, 730.98, 730.99, 996.60, 996.66, 996.67, 996.69, 998.5, 998.51, 998.59, 998.6 CPT: 10140, 10160, 10180, 12021, 13160, 20000, 20005, 26990, 26991, 26992, 27030, 27070, 27090, 27091, 27122, 27301, 27303, 35860 *TKA:* Procedures: 84.56, 86.01, 86.04, 86.22, 86.28 ICD-9: 686.8, 686.9, 711.00, 711.05, 711.06, 711.08, 711.09, 711.40, 711.45, 711.46, 711.48, 711.49, 711.90, 711.95, 711.96, 711.98, 711.99, 730.00, 730.05, 730.06, 730.08, 730.09, 730.10, 730.15, 730.16, 730.18, 730.19, 730.20, 730.25, 730.26, 730.28, 730.29, 730.90, 730.95, 730.96, 730.98, 730.99, 996.60, 996.66, 996.67, 996.69, 998.5, 998.51, 998.59, 998.6 CPT: 10140, 10160, 10180, 12021, 13160, 20000, 20005, 27301, 27303, 27310, 27488, 27603, 27604, 27607, 35860 *Vascular* Procedures: 54.0*, 54.19*, 86.01, 86.04, 86.22, 86.28 ICD-9: 686.8, 686.9, 996.6, 996.62, 998.51, 998.59, 998.6 CPT: 10140, 10160, 10180, 12021, 13160, 2000, 2005, 35840, 35840*, 35903, 35907* *only following a central vascular procedure (Includes outpatient codes)	Vasc: 60d TKA/ THA: 365d	Yes	Internal, sole
Curtis 2004	TKA, THA, vascular	ICD-10 AM mapped to Cadwallader et al (+ T84.41)	Unclear	Unclear	Internal, sole
Gerbier 2011	All	ICD-10: T814, T815, T816, T826, T827, T835, T836, T845, T846, T847, T857, O860 *refer to manuscript for extended selection	LoS	No	Internal, sole
Haley 2012†	CABG, colon, THA	ICD-9 : 5912, 567.21, 567.9, 682.2, 730.08, 730.25, 730.28, 995.91, 995.92, 996.66, 996.67, 996.77, 997.4, 998.11, 998.12, 998.30, 998.31, 998.32, 998.51, 998.59, 998.83, 38.11, 38.40, 41.09, 41.11, 41.12, 41.7, 41.85,	30/365	Yes	External
Hollenbeak 2011	General & vascular	ICD-9 : 998.59	30	Unclear	Internal, sole
Julian 2006	All	ICD-9: 730.09, 730.20-39, 730.90-730.99, 890.0-890.2, 891.0-891.2, 894.0-894.2, 996.61-996.63, 996.66, 996.67, 996.71, 996.72, 998.0, 998.31, 998.32, 998.51, 998.59, 998.6, 998.83, 999.3, 320.81, 320.82, 320.89, 320.0-320.3, 320.7, 320.9, 321.0-321.4, 321.8, 322.0, 322.9, 324.0, 324.1, 324.9, 420.90, 420.91, 420.99, 421.9, 422.90, 422.91, 513.1, 519.2, 682.1-682.4, 682.6, 682.7, 682.9, 728.0, 730.00-730.08 (PHC4 selection, secondary codes only)	LoS	No	External
Kanerva 2009	All	ICD-10 (first 3 slots): O86, T81.4, T84.5, T84.68, T82.7or A40, A41, A46, A48.8, A49, M00, M01, M46*B95.7 with or without T72.1, T21.2, Y83, Y84, Y88	LoS	No	Internal, sole

Study	Procedure	Codes used (Inpatient only, primary & secondary unless specified)	Duration follow-up	Includes readm	Purpose of algorithm
Lawson 2012	All	ICD-9: 998.5, 998.51, 998.59 Also includes outpatient	30	Yes	External
Lee 2011*	Gastric cancer patients	ICD-10 Mapped to PHC4 selection (see Julian)	Los	No	Internal, comb
Leth 2006†	Orthopedic Abdominal	ICD-10, T81.4	LoS	No	Internal, comb
Moro 2004	NNIS Procedures	ICD-9: three different sets of codes Group 1: 958.3, 996.60-996.69, 998.5, 998.51, 998.59 Additional group 2: group 1 + 254.1, 320.0, 320.2, 320.3, 320.8, 320.9, 321.0, 324.0, 324.1, 324.9, 2360.01, 360.00, 360.02, 360.04, 370.55, 373.13, 383.0-, 420.99, 421.0, 421.9, 424.90, 422.0, 422.90, 422.92, 422.99, 420.90, 447.6, 451-, 461.0-461.9, 475, 478.22, 478.24, 510.0-510.9, 513.0, 513.1, 519.2, 527.3, 528.3, 567.-, 566, 569.5, 572.0, 577.0, 590.10-590.11, 590.80, 590.2, 597.0, 597.80-, 599.0, 601.2, 604.0, 611.0, 614.0, 614.3, 614.5, 614.8, 614.9, 615.0, 615.9, 616.0, 616.1-, 675.10, 683, 711.0-, 711.4-, 711.6-, 711.8-, 711.9-, 727.00, 727.3,730.00-730.09.. Group 3: group 1 + group 2 + 998.6, 998.83, 999.3	LoS	No	Internal, comb
Sherman 2006*	All	ICD-9 as selected by PHC4 (see Julian)	LoS	No	External
Spolaore 2005	All	ICD-9: 998.5, 996.6 (not 996.64) or 958.3	LoS	No	Internal, comb
Stevenson 2008	All	Secondary ICD-9 as selected by PHC4 (see Julian). Outpatient codes unclear.	30/365	Yes	External
Tinelli 2011*	All	ICD-9 (up to 5 secondary): 264 codes, details not specified (no reply from corresponding author) Rehabilitation facility only 3x	LoS	No	Internal, sole
Verelst 2010	All	ICD-9: 998.51 or 998.59 in secondary diagnosis field, excl primary diagnoses for SSI and age < 16.	LoS	No	External
Yokoe 2012	Hysterectomy, vascular, colorectal	ICD-9: 998.5, 998.51, 998.59, 996.60, 996.62	30/365	Yes	Internal, comb

Abbreviations: CABG – coronary artery bypass graft, LoS – Length of Stay, PHC4 – Pennsylvania Healthcare Cost Containment Council, SSI – surgical site infection, THA – total hip arthroplasty, TKA – total knee arthroplasty,

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

CLABSI

Study	Denominator	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Cevasco 2011	Within algorithm	PSI 7, version 3.1: ICD-9: 999.3, 999.62 in secondary diagnosis field; not PoA Excludes some high-risk patients based on primary diagnoses	External
Cima 2011	Within algorithm	Idem Cervasco 2011	External
Moehring, 2013	Within algorithm	CMS rule: 999.31 + PoA negative	External
Pokorny, 2006*	Unclear	ICD-9 codes for 'clinical infection: 038, 038.0, 038.1, 038.2, 038.3, 038.4, 038.8, 038.9, 360.0, 360.1, 480, 481, 482.0, 482.1, 482.2, 482.4, 482.8, 482.9, 483, 484, 485, 486, 590.10, 595.0, 599.0, 646.60, 646.61, 646.62, 646.63, 646.64, 646.6[0-4], 670, 670.02, 670, 674.34 [4], 790.7, 421.0 , 421.1, 421.9, 996.6, 996.61, 996.62, 996.64, 996.69, 998.5, 998.51, 998.59	Internal, comb
Scanlon 2008	Within algorithm	Pediatric quality indicator: 999.3, 999.62 (does not include PoA indicator) Denominator: Age 0 – 17, admitted without infection as primary diagnosis,	External
Sherman 2006*	Within algorithm	ICD-9: specified by PHC4 (secondary diagnoses) 0380, 038.1, 038.11, 038.19, 038.2, 038.3, 38.40, 38.41, 38.42, 38.43, 38.44, 38.49, 38.8, 38.9, 790.7, 995.9, 995.91, 995.92, 995.92	External
Stamm 2012	Identified by traditional surveillance	ICD-9; details not specified (no reply from corresponding author)	Internal, sole
Stevenson 2008	Patients with a positive blood culture	ICD-9: specified by PHC4 (secondary diagnoses) 0380, 038.1, 038.11, 038.19, 038.2, 038.3, 38.40, 38.41, 38.42, 38.43, 38.44, 38.49, 38.8, 38.9, 790.7, 995.9, 995.91, 995.92, 995.92	External
Stone 2007	Within algorithm	PSI 7, version 2.1	External
Tehrani 2013	Sens: patients in routine surveillance PPV: within code selection	CMS HAC rule: 999.31 + PoA negative	External
Zrelak 2011	Within algorithm	PSI 7, version 3.1: ICD-9: 999.3, 999.62 in secondary diagnosis field; not PoA Excludes some high-risk patients from denominator based on primary diagnoses	External

Abbreviations: CLABSI – central-line associated bloodstream infection, CMS – Centers for Medicare and Medicaid Services, HAC – Hospital-acquired condition, PoA – present on Admission, PHC4 – Pennsylvania Health Care Cost Containment Concil, PSI – patient safety indicator,

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

Bloodstream infection/Sepsis

Study	Codes used (Inpatient only, Primary & secondary unless specified)	Purpose of algorithm
Best 2002	ICD-9: 998.0 - 38.0 - 38.9, 785.5, 785.59	External
Braun 2006†	Compares several algorithms at the aggregate level. Does not detail all algorithms	External
Cevasco 2011a	PSI 13, version 3.1 Secondary ICD9 diagnoses (not PoA) : 038.0, 38.1, 038.10, 38.11, 038.12, 38.19, 38.2, 0383, 785.52, 785.59, 998.0, 995.91, 995.92, 038.4, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 0389. Numerator: Patients aged over 18 undergoing an elective procedure with LoS > 3 days . Excludes patients with principal diagnosis of infection/sepsis, patients with infection PoA, patients with cancer/immunosuppression and obstetric admissions.	External
Cevasco 2011b	PSI 13, version 3.1 (idem Cevasco 2011a)	External
Cima 2011	PSI 13, version 3.1 (idem Cevasco 2011a)	External
Gerbier 2011	ICD-10: A021, A207, A217, A227, A241, A267, A280, A327, A392, A393, A394, A40-, A41-, A427, A483, A499,A548, B007, B377, O080, O753, O85, P3600, P3610, P3620,P3630, P3640, P3650, P3680, P3690	Internal, sole
Hougland 2008	ICD-9: 038.0, 038.10, 038.11, 038.19, 038.3, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9, 790.7	Ext
Kanerva 2009	ICD-10 (first 3 slots): A40, A41, B37, R 50.9, J15.9, J 18.9, K80, N30 with or without Y82, Y83	Internal, sole
Koch 2012	PSI 13, version 4.2 Secondary ICD9 diagnoses (not PoA) : 038.0, 38.1, 038.10, 38.11, 038.12, 38.19, 38.2, 0383, 785.52, 785.59, 998.0, 995.91, 995.92, 038.4, 038.41, 038.42, 038.43,038..44, 038.49, 038.8, 0389. Numerator: Patients aged over 18 undergoing an elective procedure with LoS > 3 days . Excludes patients with principal diagnosis of infection/sepsis, with infection PoA, with cancer/immunosuppression and obstetric admissions.	Ext
Lawson 2012	ICD-9: 038*, 785.52, 995.91, 995.92, 998.0, 998.59, 999.31 (incl outpatient)	External
Lee 2011*	ICD-10 Mapped to PHC4 selection: 0380, 038.1, 038.11, 038.19, 038.2, 038.3, 38.40, 38.41, 38.42, 38.43, 38.44, 38.49, 38.8, 38.9, 790.7, 995.9, 995.91, 995.92, 995.92. No reply from corresponding author regarding exact code selection.	Internal, comb
Murff 2011	PSI 13, version 3.1	External
Ollendorf 2002	Presence of codes indicative of sepsis on first 9 positions of UB-92 bill 003.1, 020.2, 022.3, 036.2, 038.0 038.1, 038.2, 038.3, 038.4, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9, 054.5, 790.7,	Internal, sole
Romano 2009	PSI 13 version 2.1 (ICD-9). Original: any 38.xx code in secondary diagnosis field. Revised: 38.xx code in secondary diagnosis field or code 998.0, 998.1, 785.59, 785.5, 785.52 No accounting for PoA. Denominator same as other PSI studies	External
Scanlon 2008	PDI (ICD-9). Numerator: secondary diagnosis code for sepsis, without PoA indicator Denominator: Age 0-17, non-neonate, LoS > 4 days, without sepsis of infection as primary diagnosis	External
Verelst 2010	PSI 13, version 3.1 (see Cevasco 2011a)	External

Abbreviations: CLABSI – central-line associated bloodstream infection, CMS – Centers for Medicare and Medicaid Services, HAC – Hospital-acquired condition, LoS – length of stay, PoA – present on Admission, PHC4 – Pennsylvania Health Care Cost Containment Concil, PDI – pediatric quality indicator, PSI – patient safety indicator,

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

CAUTI

Study	Denominator	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Meddings 2010	Within algorithm (996.64)	ICD-9: Secondary code 112.2, 590.10, 590.11, 590.2, 590.3, 590.80, 590.81, 595.0, 597.0, and 599.0 with or without PoA.	External
Pokorny 2006*	Unclear	ICD-9 codes for 'clinical infection, see under CLABSI	Internal, comb
Sherman 2006*	Within algorithm	ICD-9: 590.00, 590.01, 590.1, 590.11, 590.2, 590.3, 590.8, 590.9, 595.0, 595. 1, 595.2, 595.3, 595.81, 595.89, 595.9, 599.0, 9975.	External
Zhan 2009	Within algorithm 1. Procedure code 57.94 or 57.95 2. Claims with major surgery 3. Claims with any ICD-9 procedure code	ICD-9 in secondary diagnosis fields: 996.64, 112.2, 590.10, 590.11, 590.2, 590.8, 590.81, 590.9, 595.0, 595.3, 595.4, 595.89, 595.9, 597.0, 597.80, 599.0 Excluding discharges with primary discharge codes for sepsis or infection or any discharge code for immunosuppression (in analogy to PSI)	External

Abbreviations: CAUTI – catheter-associated urinary tract infection, PoA – present on admission, PSI – patient safety indicator

UTI

Study	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Best 2002	ICD-9: 599.0, 590.1 - 590.9, 595.0 - 595.9	External
Campbell 2011†	Requested from corresponding authors; not available	Internal, sole
Gerbier 2011	ICD-10: N300, N34-, N390, O862, O863, T835	Internal, sole
Heisler 2009	Hospital adaptation of ICD-9 codes, equivalent to 599.0 and 999.64	Internal, sole
Julian 2006	ICD-9: 590.00, 590.01, 590.10, 590.11, 590.2, 590.3, 590.80, 590.9, 595.0-595.3, 595.81, 595.89, 595.9, 599.0, 997.5 (secondary codes only, PHC4)	External
Kanerva 2009	ICD-10: N30, N39, A41, R50.9; first three slots only	Internal, sole
Landers 2010	ICD-9: 599.0	Internal, sole
Lawson 2010	ICD-9: 112.2, 590.1*, 590.3, 590.8*, 595.0, 595.30, 599.0, 996.64	External
Lee 2011*	ICD-10 Mapped to PHC4 selection (see Julian) No reply from corresponding author regarding exact code selection.	Internal, comb
Tinelli 2011*	ICD-9 (up to 5 secondary): 264 codes, details not specified (no reply from corresponding author) Rehabilitation facility only	Internal, sole

Abbreviations: UTI –urinary tract infection, PHC4 – Pennsylvania Health Care Cost Containment Council.

Table S6: Administrative data algorithm, by HAI type, cont'd

*: studies presenting only accuracy estimates aggregated over multiple types of HAI.
†: studies assessing an algorithm combining multiple sources of data that did not allow for data-extraction for administrative data only.

VAP

Study	Denominator	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Drees 2010	Within algorithm	ICD-9: 999.9	Internal, sole
Julian 2006	Within algorithm (code for mechanical ventilation)	ICD-9 (secondary codes only according to PHC4): 480.0-480.3, 480.8, 480.9, 481, 482.0-482.2, 482.30-482.32, 482.39-482.41, 482.82-482.84, 482.89, 482.9, 483.0, 483.1, 483.8, 485, 486, 487.0, 482.49, 482.81	External
Pokorny 2006*	Unclear	ICD-9 codes for 'clinical infection, see under CLABSI	Internal, comb
Sherman 2006*	Within algorithm	ICD-9 (secondary codes only according to PHC4): 480.0-480.3, 480.8, 480.9, 481, 482.0-482.2, 482.30-482.32, 482.39-482.41, 482.82-482.84, 482.89, 482.9, 483.0, 483.1, 483.8, 485, 486, 487.0, 482.49, 482.81	External
Stamm 2012	Identified by traditional surveillance	ICD-9; details not specified (no reply from corresponding author)	Internal, sole
Stevenson 2008	Patients with ventilator procedure code (31.1, 31.2, 31.29, 31.21, 96.04, 96.7, 96.70, 96.71, 96.72)	ICD-9 (secondary codes only according to PHC4): 480.0-480.3, 480.8, 480.9, 481, 482.0-482.2, 482.30-482.32, 482.39-482.41, 482.82-482.84, 482.89, 482.9, 483.0, 483.1, 483.8, 485, 486, 487.0, 482.49, 482.81	External
Verelst 2010	Belgian nomenclature code for artificial ventilation (211046)	PSI version 3.1 ICD-9 codes for pneumonia in secondary field. Excludes primary diagnosis of pneumonia or 997.3, or viral pneumonia, immunocompromised, < 16 years.	External

Abbreviations: PHC4 – Pennsylvania Health Care Cost Containment Council, PSI – patient safety indicator, VAP – ventilator-associated pneumonia.

Pneumonia (sometimes also including VAP)

Study	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Best 2002	ICD-9: 997.3, 480.0 - 487.0	External
Gerbier 2011	ICD-10: J10-, J11-, J12-, J13-, J14-, J15-, J16-, J17- , J18-,	Internal, sole
Hougland 2008	ICD-9: 481, 482.0, 482.1, 482.2, 482.30, 482.31, 482.32, 482.39, 482.40, 482.41, 482.49, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 483.8, 485, 486.	External
Kanerva 2009	ICD-10: J13, J15.9, J18.9, J20.9, J60.9, J05, J38.5, B59, R91; first three slots only	Internal, sole
Lawson 2012	ICD-9: 39.1, 1124, 1179, 1363, 4466.19, 480*, 481, 482*, 483*, 4841, 4846, 4847, 485, 486, 4870, 507*, 5130, 5168, 997.31, 997.39	External
Lee 2011*	ICD-10 Mapped to PHC4 selection (see Julian). No reply from corresponding author regarding exact code selection.	Internal, comb
Murff 2011	PSI version 3.1 for pneumonia as a component of *Failure to Rescue (PSI 4)* ICD-9 codes: 482.0, 482.1, 482.2, 482.3, 482.3, 482.30, 482.31, 482.32, 482.39, 482.4, 482.40, 482.41, 482.49, 482.8, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 485, 486, 507.0 514, excluding cases with a pre-existing condition of pneumonia or 997.3, with any diagnosis code for viral pneumonia, MDC 4 (diseases/disorders of respiratory system) or with any diagnosis of immunocompromised state In this study, the PSI patient population was limited to patients eligible for both the VASQIP measures and PSI criteria (see the article for details).	External

Abbreviations: PHC4 – Pennsylvania Health Care Cost Containment Council, PSI – patient safety indicator, VAP – ventilator-associated pneumonia.

Other

Study	Target infection	Codes used (Inpatient only, primary & secondary unless specified)	Purpose of algorithm
Van Mourik 2013	Drain-related meningitis	ICD-9: 112.83, 320.00 – 320.9, 322.00 – 322.9, 324.00 – 324.9, 349.10, 792.00, 996.60, 996.63, 996.70, 996.75, 997.00, 997.01, 997.09, 998.50 – 998.59, 999.30 – 999.39 Patients at risk identified by manual surveillance	Internal, sole
Yokoe 2001†	Post-partum infection	ICD9: 670.2, 670.04, 599.0, 674.34, 675.14, 675.24, 998.5 COSTAR (ambulatory): DA140, DC150, DC408, DH140, DL101, DM153, DR180	Internal, comb

Abbreviations: COSTAR: Computer-stored ambulatory record.