Major article

An electronic surveillance tool for catheter-associated urinary tract infection in intensive care units

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Background: Traditional methods of surveillance of catheter-associated urinary tract infections (CAUTIs) are error-prone and resource-intensive. To resolve these issues, we developed a highly sensitive electronic surveillance tool.

Objective: To develop an electronic surveillance tool for CAUTIs and assess its performance.

Methods: The study was conducted at a 947-bed tertiary care center. Patients included adults aged ≥18 years admitted to an intensive care unit from January 10 to June 30, 2012, with an indwelling urinary catheter during their admission. We identified CAUTIs using 4 methods: traditional surveillance (TS) (i.e., manual chart review by ICPs), an electronic surveillance (ES) tool, augmented electronic surveillance (AES) (i.e., ES with chart review on a subset of cases), and reference standard (RS) (i.e., a subset of CAUTIs originally ascertained by TS or ES, confirmed by review). We assessed performance characteristics to RS for reviewed cases.

Results: We identified 417 candidate CAUTIs in 308 patients; 175 (42.0%) of these candidate CAUTIs were confirmed by RS. Compared with RS, the sensitivities of TS, ES, and AES were 43.8% (95% confidence interval [CI], 26.4%-62.3%), 100.0% (95% CI, 89.1%-100.0%), and 100.0% (95% CI, 89.1%-100.0%). Specificities were 82.5% (95% CI, 75.3%-88.4%), 2.8% (95% CI, 0.8%-7.0%), and 100.0% (95% CI, 97.5%-100.0%).

Conclusions: Electronic CAUTI surveillance offers a streamlined approach to improve reliability and resource burden of surveillance.

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During 2012, the Joint Commission for Accreditation and Certification of Healthcare Organizations adopted catheter-associated urinary tract infection (CAUTI) prevention as a National Patient Safety Goal. Beginning January 1, 2012, as a condition of participation in repayment programs, the Centers for Medicare and Medicaid Services mandated CAUTI reporting from all intensive care units (ICUs) to the National Healthcare Safety Network (NHSN), a patient and health care personnel safety surveillance system managed by the Centers for Disease Control and Prevention (CDC). At present, this mandated reporting requires trained personnel, usually infection control practitioners (ICPs), to review the charts of all ICU patients to identify those meeting criteria for...
CAUTI, a process that is exceedingly time- and labor-intensive and demands substantial staffing adjustments.5–6

With chart review continuing to serve as the gold standard for CAUTI surveillance, efficient identification of CAUTI by hospitals remains elusive and is an impediment to improvement in patient outcomes and infection control practices.4 We developed an efficient and practical mechanism for CAUTI identification.

MATERIALS AND METHODS

Massachusetts General Hospital (MGH) is a 947-bed teaching hospital in Boston, Massachusetts, with 8 adult ICUs (~ 166 ICU beds). The MGH study population included all adult patients (aged ≥18 years) with an indwelling urinary catheter at any time while admitted to an ICU between January 10 and June 30, 2012. The study was approved by the Partners Human Research Committee (protocol No. 2011-P-001471). The requirement for informed consent was waived.

At the time of the study, the CDC and NHSN defined a CAUTI as a symptomatic urinary tract infection or asymptomatic bacteremic urinary tract infection occurring in any patient from the time an indwelling urinary catheter is inserted until 48 hours beyond removal (Table 1).

Table 1

| 2012 Centers for Disease Control and Prevention/National Healthcare Safety Network (NHSN) surveillance definition of catheter-associated urinary tract infection (CAUTI) in adults. For all patients included in the study, an indwelling urinary catheter* was in place or removed within 48 hours of the time of specimen collection |
|---------------------------------|---------------------------------|---------------------------------|
| Symptomatic CAUTI with high colony count | Symptomatic CAUTI with intermediate colony count | Asymptomatic bacteraemic CAUTI |
| Signs and symptoms7 | Fever (>38°C) with no other recognized cause, suprapubic tenderness, urgency, frequency, dysuria, or CVA pain | Fever (>38°C) with no other recognized cause, suprapubic tenderness, urgency, frequency, dysuria, or CVA pain | Patient must have no signs or symptoms (exception: if aged ≥65 years, fever does not disqualify) |
| Urine culture | Colony count | ≥10^5 CFU/mL |
| No. species | ≤2 | >10^2 and <10^5 CFU/mL |
| Urinalysis | Not required | ≥10^5 CFU/mL |
| Blood culture | Not required | Not required |

For the review of TS-identified charts, the investigators were blinded to each other’s decision and to the initial identification method. Taken together, chart review occurred for a selection of 175 of the
417 candidate CAUTIs (42.0%) initially identified by either TS or ES. Discordance between the 2 investigators on case assignment triggered a second chart review, discussion, and consensus. The 175 investigator-reviewed cases form the RS.

**Candidate CAUTI and confirmed CAUTI case ascertainment**

We calculated the frequencies and percentages of candidate CAUTIs ascertained by TS, ES, and AES, as well as the number of RS CAUTI cases confirmed by investigator chart review. For the candidate CAUTIs selected for investigator review, we calculated a kappa statistic to assess agreement between the 2 study investigators’ CAUTI designations. Interpretation of kappa values for interrater agreement were defined as priori, with 0.00-0.20 considered poor, 0.21-0.40 considered fair, 0.41-0.60 considered moderate, 0.61-0.80 considered good, and 0.81-1.00 considered very good.7

To compare candidate CAUTI case designations by method of surveillance with RS, we constructed 2 × 2 contingency tables and a summary contingency table comparing all methods. We determined the sensitivity, specificity, and positive and negative predictive values of all methods compared with RS for the investigator-reviewed cases. For all test performance characteristics, we report exact binomial 95% confidence intervals (CIs).

We constructed a 2 × 2 table to compare case designations by TS and ES among the subset of candidate CAUTIs reviewed by study investigators and calculated a kappa statistic to assess the influence of investigator versus ICP status on final CAUTI determination.

**Validation of the electronic algorithm**

Using data collected during the study period, the electronic algorithm was developed over multiple iterations, with the goal of >95% ascertainment of cases identified by TS. From July 1 to September 30, 2012, we conducted a separate, formal validation process to determine the electronic algorithm’s ability to ascertain cases identified by TS in the absence of revisions to the algorithm. Only candidate CAUTIs identified by TS that were determined on investigator review to meet the NHSN definition were included in calculations of the percentage of TS cases ascertained by the electronic algorithm.

**RESULTS**

**Candidate CAUTI and confirmed CAUTI case ascertainment**

From January 10 through June 30, 2012, 10,397 urine cultures were obtained hospitalwide, and 17,239 indwelling urinary catheter-days were recorded among 1,683 ICU patients. Using a combination of TS and ES, we identified 417 candidate CAUTIs in 308 patients during the study period (Fig 1). TS alone identified 8 potential cases that were not identified by ES (out of 417; 1.9%), whereas 90 (out of 417; 21.6%) were detected by both TS and ES. ES alone generated the majority of the candidate CAUTIs that were not identified by TS (319 out of 417; 76.5%).

Of the 417 candidate CAUTIs originally detected, a random subset of 175 candidate CAUTIs were selected for chart review by study investigators (Fig 1). Within this subset of investigator-reviewed candidate CAUTIs, 4 were identified by TS alone (4 out of 175; 2.3%), whereas 35 were identified by both TS and ES (35 out of 175; 20.0%), and 136 were detected by ES alone (136 out of 175; 77.7%), reflecting similar distributions to the overall sample. Investigator review confirmed 32 CAUTIs in 22 patients (RS). Agreement on case designation between study investigators (HEH and ESS) on initial review was considered good (κ = 0.71; 95% CI, 0.57-0.85), with concordance achieved for 92% of cases (161 out of 175). Fourteen cases (8%) required a second review and discussion by the study investigators before final case designation.

**Characteristics of RS-Confirmed CAUTI cases**

The majority of patients with confirmed CAUTI on investigator review were women (77.3%) and median age was 72.5 years (range, 32-94 years). Median length of stay was 13.0 days (range, 4.6-77.7 days); the number of indwelling urinary catheter-days for each period of catheterization ranged from 3 to 39 days (median, 8 days). Three patients with confirmed ICU-based CAUTI died during the hospitalization (13.6%).

**Comparisons of surveillance methods to the RS**

**TS**

TS detected 14 of 32 CAUTIs identified by the RS. Overall concordance of case classification between TS and RS was 75.4% (132 out of 175; Table 2). Compared with RS, the sensitivity of TS was 43.8% (14 out of 32; 95% CI, 26.4%-62.3%), whereas specificity was 82.5% (118 out of 143; 95% CI, 75.3%-88.4%) (Table 3).
ES
ES identified all 32 investigator-confirmed CAUTIs, but properly classified only 4 of 143 candidate CAUTIs as true negatives (Table 2). Overall concordance of case classification was 20.6% (36 out of 175). Compared with RS, the sensitivity of ES was 100.0% (95% CI, 89.1%-100.0%), whereas specificity was 2.8% (4 out of 143; 95% CI, 0.8%-7.0%) (Table 3). If fever, as documented in the paper chart and recorded in the investigator chart review, was an electronically searchable criterion and could be incorporated into the electronic algorithm, the specificity of the algorithm alone increased to 100.0% (95% CI, 97.5%-100.0%), whereas sensitivity decreased to 78.1% (95% CI, 60.0%-90.7%).

AES
AES achieved complete concordance with RS, classifying 32 of 32 true positive investigator-confirmed CAUTI cases and 143 of 143 true negatives (Table 2). Thus, when compared with RS, the sensitivity of AES was 100.0% (95% CI, 89.1%-100.0%), and specificity was 100.0% (95% CI, 97.5%-100%) (Table 3).

Comparison of TS with ES
Of the 39 candidate CAUTIs identified by TS for targeted chart review, 4 potential cases were not ascertained by ES alone. Upon review of these 4 cases, 2 were found to have a urinalysis outside of the algorithm’s 48-hour time window, 1 had a urine culture that was >1 week removed from the CAUTI event date, and 1 was attributed to the wrong medical record number. Chart review by ICPs and study investigators achieved 75.4% concordance (132 out of 175), but agreement was only considered fair ($\kappa = 0.24$; 95% CI, 0.07-0.41). Less than one-half of all confirmed CAUTI (43.8%; n = 14) were detected by all 3 alternative surveillance methods: TS, ES, and AES. More than 80% of the candidate CAUTI detected by the ES system were neither detected by TS nor confirmed by investigator review as part of AES (Table 4).

Validation of the ES system
From July 1 through September 30, 2012 (after the initial enrollment period), TS identified 46 additional candidate CAUTIs, whereas ES identified 206. Upon review of the 46 TS candidates by study investigators, 5 were determined not to meet NHSN criteria. Of the 41 candidates reported by TS and confirmed to meet NHSN microbiology and laboratory criteria by investigator review, ES detected 40 cases (97.6%). The single case missed by ES was due to correction of a urine culture logging error made by the microbiology laboratory.

DISCUSSION

Traditional CAUTI surveillance methods—grounded in bedside rounding, manual patient chart review, and the subjective implementation of multidimensional and often-evolving NHSN definitions—remain the current standard in hospital-acquired infection identification. These methods are error-prone, time-consuming, and susceptible to assessment bias in case ascertainment.  

As electronic medical records become more robust, investigators and practitioners have sought to develop computer-aided surveillance systems either to completely automate infection detection or to automate the identification of patients with a high probability of infection. For CAUTI surveillance in particular, investigators at several institutions have created electronic algorithms to aid in CAUTI identification. To date, these efforts have incorporated either ICD-9 coding or traditional surveillance by manual chart review as the RS, both of which are not only retrospective but have also been shown to misrepresent the “true” CAUTI rate.

We developed an electronic algorithm-based surveillance tool to streamline prospective CAUTI identification at a large, urban teaching hospital. Application of our ES system to query multiple hospital databases to identify CDC/NHSN-defined CAUTIs achieved >97% ascertainment of confirmed CAUTI reported by TS during both the study time frame and a period of external validation.

Our ES system was never intended to function in isolation as a fully automated surveillance system, and its specificity of <5% reflects this design. Rather, the computerized algorithm was developed with the goal of producing a list of candidate CAUTIs for targeted chart review, at which point signs and symptoms of infection as defined by the CDC/NHSN could be assessed. When combined with confirmatory chart review, the ES system achieved nearly perfect sensitivity and specificity compared with the RS, more than doubling the positive predictive value of TS. Moreover, these improvements in surveillance method performance characteristics complemented substantial reductions in time and in the complexity of manual chart review and data documentation tasks. During the study period, ICPs evaluated a total of 10,397 urine cultures and manually cross-checked these cultures with patients’ indwelling urinary catheter status, reviewing 17,239 indwelling urinary catheter-days. If our ES system had been available during this time period, the number of urine cultures that the ICPs would have needed to review would have decrease by 25-fold to 409 cultures and the system would have obviated the need for manual review of catheter-days. The reduction in resources utilized with this alternative approach, although not possible to quantify with precision, is nevertheless likely to be substantial given the sheer reduction in volume of patient-level results to review. We anticipate that the effect on resource use will expand as regulatory mandates expand; for example, as of January 2015, CAUTI surveillance in all adult and pediatric medical and surgical wards is required for participation in the Centers for Medicare and Medicaid services Hospital Inpatient Quality Reporting Program.

Both full and partial automation of surveillance systems for health care-associated infections offer several potential advantages over TS. Following a development and validation period, fully automated algorithms require minimal input from infection control staff beyond occasional quality control audits or adjustments to the program due to changing surveillance definitions. Moreover, fully automated systems that search only objective electronic data may virtually eliminate reliance on subjective aspects of surveillance definitions. By making case criteria completely explicit and

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Table 2
Comparison of alternative methods of catheter-associated urinary tract infection (CAUTI) surveillance with the reference standard

<table>
<thead>
<tr>
<th>Reference standard</th>
<th>CAUTI</th>
<th>Not CAUTI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional surveillance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Candidate CAUTI</td>
<td>14</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>Not CAUTI</td>
<td>18</td>
<td>118</td>
<td>136</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>143</td>
<td>175</td>
</tr>
<tr>
<td>Electronic surveillance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Candidate CAUTI</td>
<td>32</td>
<td>139</td>
<td>171</td>
</tr>
<tr>
<td>Not CAUTI</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>143</td>
<td>175</td>
</tr>
<tr>
<td>Augmented electronic surveillance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Candidate CAUTI</td>
<td>32</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>Not CAUTI</td>
<td>0</td>
<td>143</td>
<td>143</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>143</td>
<td>175</td>
</tr>
</tbody>
</table>

NOTE. Values are presented as numbers.
NOTE. Values are presented as % (95% confidence interval).

Table 3
Performance characteristics of alternative methods of catheter-associated urinary tract infection surveillance compared with the reference standard

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional surveillance</td>
<td>43.8 (26.4-62.3)</td>
<td>82.5 (75.3-88.4)</td>
<td>35.9 (21.2-52.8)</td>
<td>86.8 (79.9-92.0)</td>
</tr>
<tr>
<td>Electronic surveillance</td>
<td>100.0 (89.1-100.0)</td>
<td>2.8 (0.8-7.0)</td>
<td>18.7 (13.2-25.4)</td>
<td>100.0 (39.8-100.0)</td>
</tr>
<tr>
<td>Augmented electronic surveillance</td>
<td>100.0 (89.1-100.0)</td>
<td>100.0 (97.5-100.0)</td>
<td>100.0 (89.1-100.0)</td>
<td>100.0 (97.5-100.0)</td>
</tr>
</tbody>
</table>

standardizing case-finding methodologies, automation increases consistency across surveillance sites and practitioners, thus minimizing assessment bias in case ascertainment. This increases the reliability of comparisons between healthcare settings and improves the ability to evaluate trends over time.

Unless all subjective criteria are eliminated from the NHSN CAUTI case definition, there will continue to be a human dimension to surveillance. Although fully automated systems may claim more absolute efficiency and standardization, partial automation of surveillance similarly takes advantage of available technology for time-saving and error-reduction purposes while preserving the clinical judgment component of manual chart review. As shown by our experience, partial automation of surveillance can improve surveillance sensitivity compared with traditional surveillance.

Manual chart review is an expensive endeavor in a time with limited resources in which hospitals have an increasing number of reportable measures, many of which involve infection prevention. CAUTI surveillance represents a single task in an ever-expanding ICP job description. ICPs’ valuable time may be better spent reviewing candidate cases among an already-defined eligible patient pool or potentially intervening at the bedside to mitigate potential morbidity and mortality with the aid of prospective surveillance systems.

Despite the advantages of the AES in its current form, our study has several potential limitations. First, the RS used for comparison of the alternative methods of CAUTI surveillance may not necessarily be a gold standard, a common problem that plagues efforts to improve hospital-acquired infection surveillance. Given the nature of certain components of the NHSN CAUTI definition, even with confirmatory chart review by 2 study investigators, identified cases may have been misclassified. In many instances, the surveillance definition may bias review toward misclassification of clinically identified CAUTI given the high prevalence of asymptomatic bacteriuria in catheterized patients, as well as persistent fever with unknown source in ICU patients. A second limitation of this study is the fact that we both developed and evaluated the performance of the electronic algorithm within the same study period, potentially manufacturing 100% sensitivity of the algorithm as we incorporated changes to the program. We addressed this limitation by conducting a separate validation outside the study period, which confirmed >97% ascertainment of cases identified by TS.

CONCLUSIONS

We developed a highly sensitive, computerized surveillance tool for CAUTI based on objective criteria from the NHSN/CDC CAUTI surveillance definition.

Many of the objective data defining the infection-susceptible population are readily available electronically. The development of electronic tools to aid in identification of hospital-acquired infections is crucial given the potential for influence on patient care and increasing internal and external demands for augmented surveillance and reporting. These more efficient approaches to case identification show promise for increasing the amount of time available to ICPs for implementation of prevention efforts.

Acknowledgments

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References

List of MRNs of all patients with urine cultures printed from QC Pathfinder

ICP manual review of urine cultures

Urine Culture positive and not growing mixed bacteria?

NO  Discard

YES  ICP manual review of EMR

Urine culture with ≥1,000 CFU/ml?

YES  Paper chart obtained from bedside or requisitioned from medical records

NO  Discard

Printed list of MRNs and dates for all ICU patients with indwelling urinary catheters in place obtained by the Infection Control Unit Database Manager from the nursing care record

Patient in ICU at time of or within 48 hrs of urine collection?

YES  ICP manual cross-referencing of lists

NO  Discard

Patient had indwelling urinary catheter in place at time of urine collection?

YES  ICP manual review of EMR

≤2 species in urine culture?

YES  ICP manual review of EMR

>100,000 CFU/ml in urine culture?

NO  Discard

NO  Discard

Positive urinalysis within 48 hours of urine culture?

Candidate CAUTI

YES

Appendix Fig 1. Flow diagram of traditional surveillance demonstrating the ICPs’ protocol for performing traditional catheter-associated urinary tract infection (CAUTI) surveillance without the assistance of the electronic surveillance system. Boxes shaded in light grey indicate electronic or paper records obtained by the ICPs. White boxes and arrows describe steps taken in the ICPs’ workflow. Dark grey boxes indicate stopping points in the workflow (e.g., when a potential CAUTI is screened out and discarded or is deemed to be a candidate CAUTI). To begin, on a daily basis, a designated ICP would query the infection control unit’s Web-based repository of clinical microbiology data (QC Pathfinder; Vecna Technologies, Cambridge, Mass), generating a hospitalwide list of medical record numbers (MRNs) for all patients with urine cultures processed by the microbiology lab within 48 hours. The ICP manually reviewed this list and selected all positive urine cultures, excluding those with mixed bacteria. Next, the designated ICP searched the patients’ electronic medical record to determine which positive urine cultures met National Healthcare Safety Network (NHSN) criteria for colony growth. For cultures meeting colony growth criteria, the ICP then reviewed the patient’s history in the electronic medical record and paper chart to determine whether or not the patient was in an ICU at the time or within 48 hours of urine culture specimen collection. For all potential CAUTI, the ICP printed separate reports for each ICU and distributed these lists to the staff member covering the unit. Each ICP then provided the list of MRNs and dates to the infection control unit database manager, who accessed the computerized nursing care record and generated a list of dates on which each patient had an indwelling urinary catheter in place. The ICPs then manually cross-referenced the printed lists of positive urine cultures by MRN with the list of patient catheter-days. For all patients with co-occurring indwelling urinary catheters and positive urine cultures, the ICP reviewed the electronic medical record, the microbiological and urinalysis data, as well as the paper chart to determine whether a potential case met NHSN CAUTI criteria. All identified cases meeting CAUTI criteria were reported to the NHSN secure Internet-based surveillance system.
CAUTI Identification

Eligible patient pool identified via nursing care record

MRNs and catheter dates fed into query of the Clinical Data Repository (CDR)

Urine culture with $\geq 1,000$ CFU/ml exists between catheter start date and 48 hours after removal?

NO

No identifiable CAUTI

> 1 urine culture exists in the time frame?

YES

Return 1st positive culture

NO

No identifiable CAUTI

$
\leq 2$ species in urine culture?

YES

Other available urine culture?

NO

Positive urinalysis within 48 hours of urine culture?

NO

Positive blood culture collected within 48 hours of urine specimen?

YES

Candidate CAUTI

Record blood culture date and flag to signal additional chart review for urosepsis

NO

Positive urinalysis within 48 hours of urine culture?

YES

Cross-reference Case Management Database to determine patient location at the time of urine specimen collection

REPORT GENERATED

Appendix Fig 2. Flow diagram of electronic algorithm for a candidate demonstrating the electronic algorithm's protocol for processing information from multiple electronic databases. Boxes shaded in light grey indicate electronic databases accessed by the algorithm. White boxes and arrows describe sequential steps processed by the algorithm. Dark grey boxes indicate stopping points in the algorithm (eg, when a potential catheter-associated urinary tract infection [CAUTI] is screened out and discarded or is deemed to be a candidate CAUTI). As in traditional surveillance, the eligible patient pool of catheterized patients is identified via the electronic nursing care record. The medical record numbers and indwelling urinary catheter documentation dates for the eligible patient pool then form the basis of an automated query of the hospital’s Clinical Data Repository, a real-time data warehouse of clinical and microbiology data collected by multiple hospital systems. Based on the 2012 National Healthcare Safety Network (NHSN) surveillance definition for CAUTI, we defined a patient’s duration of CAUTI development eligibility from the first urinary catheter presence documentation date during an admission through 48 hours beyond the last documentation date. Catheterization time windows separated by more than 2 calendar days were treated as unique catheterization events. If more than 1 urine culture existed during the time frame for each report generated by the electronic algorithm, the query returned the first positive culture that met the NHSN microbiology and laboratory data requirements. The electronic algorithm determined hospital unit of assignment by selecting the inpatient location of the patient 48 hours before the urine culture collection date. If a patient was classified as a noninpatient at this time, the candidate CAUTI was assigned to the patient’s first inpatient location per NHSN guidelines, and the case was flagged for an additional review for possible urinary tract infection presence on admission. In addition, the electronic algorithm also generated a note of the number and dates of positive cultures occurring between 14 days before admission and 2 days after admission to aid in chart review determination of whether or not a urinary tract infection was preexisting. Supplementary elements of the algorithm-generated report included patient demographic characteristics, the start and end dates of a patient’s indwelling urinary catheter placement time period, patient location at the time of urine specimen collection, urine culture and urinalysis results, and an indication of whether or not a blood culture was performed within 48 hours of the positive urine culture.