Effectiveness of an automated surveillance system for intensive care unit-acquired infections

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ABSTRACT

This study assessed the effectiveness of a fully automated surveillance system for the detection of healthcare-associated infections (HCAIs) in intensive care units. Manual ward surveillance (MS) and electronic surveillance (ES) were performed for two intensive care units of the Vienna General Hospital. All patients admitted for a period longer than 48 h between 13 November 2006 and 7 February 2007 were evaluated according to HELICS-defined rules for HCAI. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and personnel time spent per surveillance type were calculated. Ninety-three patient admissions were observed, whereby 30 HCAI episodes were taken as a reference standard. Results with MS versus ES were: sensitivity 40% versus 87%, specificity 94% versus 99%, PPV 71% versus 96%, NPV 80% versus 95%, and time spent per surveillance type 82.5 h versus 12.5 h. In conclusion, ES was found to be more effective than MS while consuming fewer personnel resources.

INTRODUCTION

Healthcare-associated infections (HCAIs) are a serious threat to hospitalized patients, with more than 4 million people in Europe having an HCAI each year, resulting in almost 150 000 fatalities.[1] Patients admitted to intensive care units (ICUs) are more likely to develop an HCAI than patients admitted to other wards.[2–4] Infection control programmes in hospitals can substantially reduce infection rates,[5 6] but the surveillance component is both labor intensive and time consuming.[7]

Several infection reporting and prevention programmes have been initiated such as the National Healthcare Safety Network by the Centers for Disease Control and Prevention and the Hospitals in Europe Link for Infection Control through Surveillance (HELICS) programme. As part of these programmes, definitions and detection rules for the most common HCAI have been established.[8 9] The availability of such rules enables the creation of automated electronic HCAI surveillance systems that can lessen the burden on human personnel.

In this study, we assessed the effectiveness of a computerized ICU-acquired infection control system called MONI–ICU.[10 11] We analyzed the effectiveness of manual ward surveillance and electronic surveillance by comparing operating characteristics as well as personnel time spent with each surveillance method.

METHODS

Study setting and design

This study took place at the Vienna General Hospital, a 2133-bed tertiary care and teaching hospital, and was approved by the ethics committee of the Medical University of Vienna. In this study, we compared two surveillance methods of ICU-acquired infections, which are infections that occur later than 48 h after the patient has been admitted to an ICU. HELICS defines the following ICU-acquired infections:[8]

- Bloodstream infection (BSI-A and BSI-B)
- Pneumonia (PN1–5)
- Central venous catheter-related infection (CRI1–2)
- Catheter colonization
- Urinary tract infection (UTI-A, UTI-B, and UTI-C).

This study includes all types except for catheter colonization. The definitions of pneumonia cover both ventilator-associated and non-ventilator-associated cases, whereby ventilator-associated pneumonia applies when an invasive respiratory device was present (even intermittently) in the 48 h preceding the onset of infection. Furthermore, to classify an infection episode as a secondary episode instead of a prolonged duration of the same episode, new signs and symptoms, and radiographic evidence (for pneumonia) or other diagnostic testing are required.

Participants and study period

Two ICUs were selected for this study. Patients admitted to the ICU at the Department of Gastroenterology and Hepatology were observed between 28 November 2006 and 7 February 2007. Patients admitted to the ICU at the Department of Internal Medicine were observed between 13 November 2006 and 7 February 2007. Each patient with a recorded stay of more than 48 h was included in the study. Due to the limited personnel resources available, the goal for the study was to gather at least 1000 patient days of data.

Data collection

Manual ward surveillance

Manual ward surveillance was performed by a physician from the Clinical Institute of Hospital Hygiene who had 5 years experience in infection surveillance. Each ICU was visited at least twice a week, whereby patient data were evaluated for each day since the last visit. During a visit, the infection control specialist (ICS) filled out a report based on consultations with the attending physicians, patient charts, data from the patient data

Table 1 Overview of the main clinical and laboratory-based infection parameters in MONI–ICU

	BSI	PN	UTI	CRI
General infection parameters	Fever,* increased CRP,* leucopenia,* leukocytosis*			
Specific infection parameter	Shock,* hypotension*	Decreased gas exchange,* respiratory device present ≤48 h	Urinary catheter present ≤48 h	Shock,* hypotension,* catheter present ≤48 h
Laboratory results	Microbiology: blood cultures	Microbiology: blood cultures, BAL,* DPA,* PB cultures*	Microbiology: Urine cultures, catheter cultures	Microbiology: blood cultures, catheter cultures

*Indicates that the infection parameter is represented by a fuzzy set.
BAL, bronchoalveolar lavage; BSI, bloodstream infection; CRI, central venous catheter-related infection; CRP, C-reactive protein; DPA, distal protected aspirate; PB, protected brush; PN, pneumonia; UTI, urinary tract infection.

management system of the ICU, and the most recent microbiology and radiology results. When test results were unavailable, reports would be completed at the next visit. Completed reports were collected in a folder, and all observations and infection diagnoses were tabled in an EXCEL file. In very few and not easy to decide cases the surveyor consulted the supervisor, a physician of the Clinical Institute of Hospital Hygiene with over 6 years of experience in infection surveillance and epidemiology, before making a diagnosis. Both ICSs were aware of the study, but had no knowledge of electronic surveillance results.

Electronic surveillance

Electronic surveillance was performed by MONI–ICU, a clinical system for the detection and monitoring of ICU-acquired infections, developed at the Medical University of Vienna.[10 11] It receives clinical, laboratory and nursing data from the Philips CareVue patient data management systems in operation at the ICU wards on a daily basis. For patients' microbiology data, it is connected with the laboratory information system of the Department of Microbiology of the Vienna General Hospital. Imported administrative data (ie, a patient's identifier and admission date) are used to combine data correctly from both sources.

The set of ICU-acquired infection definitions was analyzed by medical experts and medical knowledge engineers, decomposed into medically relevant infection criteria, and formalized so that abstract linguistic infection criteria could be assigned to measured and observed patient data. Fuzzy sets were defined to capture borderline values of clinical concepts. The Arden Syntax was chosen as a suitable computer-readable format for medical knowledge representation and the processing scheme.[12 13] An overview of the main clinical infection criteria and laboratory data associated with each infection type is shown in table 1. The detection results can be viewed with a web browser, along with the scores for their associated intermediate infection criteria, raw data values and the rules that govern their interrelationship. Figure 1 shows the MONI–ICU web browser interface.

The effectiveness of electronic surveillance was determined by a diagnostic performance study.[14] Surveillance results were recalculated after the manual ward surveillance study had ended. In order to adhere to the standard for epidemiological reporting, fuzzy-graded results for infection diagnoses were excluded.

Reference standard

The reference standard was constructed by two physicians of the Clinical Institute of Hospital Hygiene who had not previously seen the manually collected surveillance results; the supervising ICS previously mentioned and a senior ICS with more than 20 years of experience in infection surveillance and epidemiology. Both ICSs scrutinized the results from both surveillance methods, and together repeated the manual ward surveillance process using all available notes and data. In case there was discordance between their results and the outcome of one of the surveillance methods, the available data would be studied until a plausible explanation was found and a consensus on the actual reference could be established.

Outcome measures

Analysis of the effectiveness of both surveillance methods was done by calculation of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Clopper–Pearson 95% CIs were calculated for all parameters.[15 16] For individual infection types, the number of true positives, false positives and false negatives for each surveillance method were mentioned. Finally, personnel time required for each surveillance method during the entire study period was also determined.

Methods for data analysis

Sensitivity, specificity, PPV, and NPV were calculated using Microsoft Excel 2007. CI calculation was done with R, a free software environment for statistical computing and graphics.

RESULTS

Data collection

One-hundred and two eligible patient admissions were reviewed comprising 1005 surveillance days. Due to missing and incomplete electronic data, the reference standard was based on the analysis of 93 admissions comprising 882 surveillance days. Seventy-five admissions were free of ICU-acquired infections and 30 infection episodes occurred in the remaining 18 admissions; 12 patients had one episode during their stay, one patient had two episodes, four patients had three episodes, and one patient had four episodes. In total, there were three BSI-A, five PN1, nine CRI1, nine CRI2 and four UTI-A episodes.

Performance

Table 2 shows the effectiveness of both surveillance methods. Manual ward surveillance failed to detect 18 episodes; three UTI-A, three BSI-A, three CRI1, eight CRI2, and one PN1 episodes were missed. Furthermore, five false positives were detected; two UTI-C, one UTI-B, one BSI-B, and one UTI-A episodes were wrongly classified. As a result, sensitivity was 40% (23–59%), specificity 94% (86–98%), PPV 71% (44–90%), and NPV 80% (71–88%).

Electronic surveillance missed four episodes; three PN1 episodes and one CRI1 episode were not detected due to missing microbiological data. One false positive was generated; a CRI2 episode was wrongly detected due to a high number of leucocytes, caused by the patient's leukemia. Consequently, sensitivity was 87% (69–96%), specificity 99% (93–100%), PPV 96% (81–100%), and NPV 95% (88–99%).

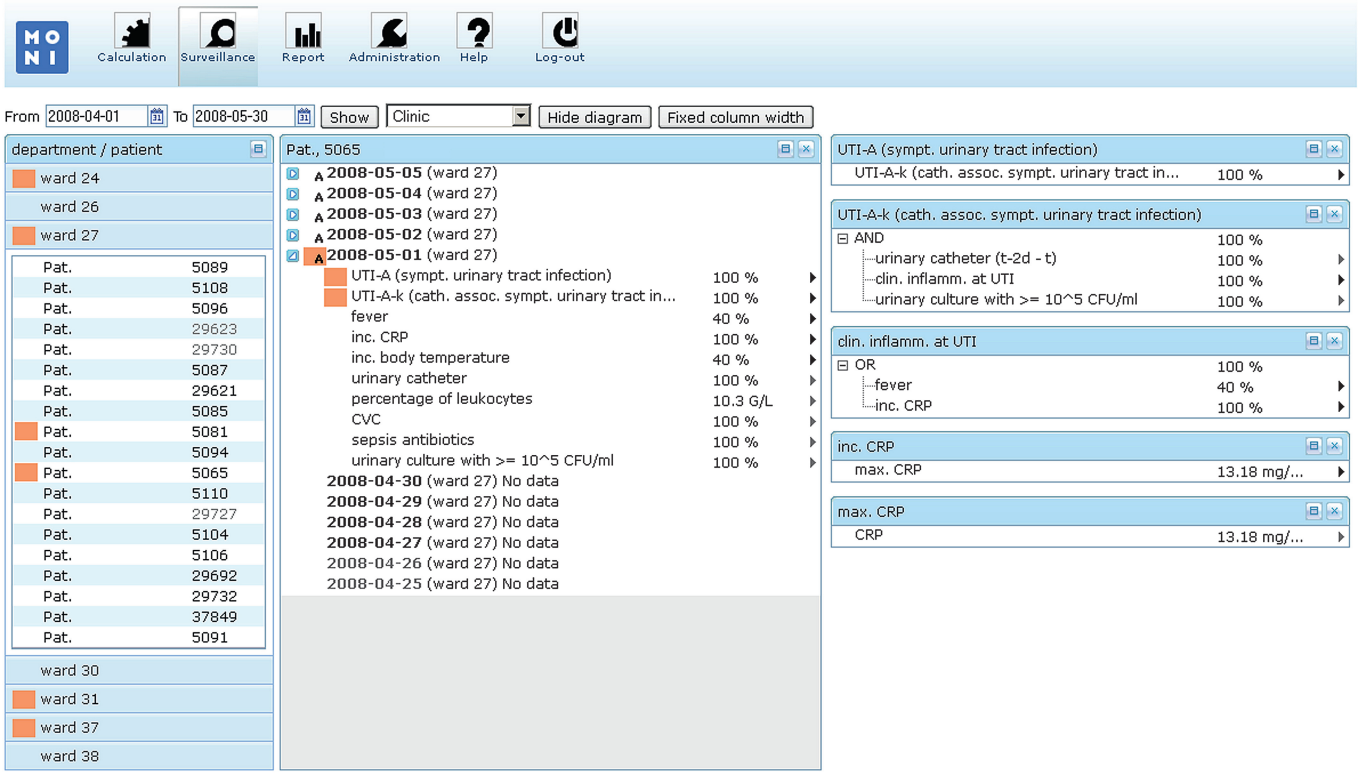

Figure 1 The MONI–ICU web browser interface. The left column shows each ward under surveillance and each patient in the selected ward for the selected period. The colored blocks indicate the presence of an ICU-acquired infection, in which a light color indicates a fuzzy result, and a dark color indicates an established infection. The middle column shows specific information for a patient on a selected day, in this case patient 5065 on 1 May 2008. The orange blocks indicate that a catheter-associated urinary tract infection has been established for this patient, and scores for relevant intermediate infection parameters are also supplied. The right column provides the user with further information on an element selected in the middle column, in this case the UTI-A element. The interface recursively shows which rules were used to calculate scores, as well as scores for individual elements in the rule. CFU, colony forming unit; CRP, C-reactive protein; CVC, central venous catheter; UTI, urinary tract infection.

When considering individual ICU-acquired infection types, electronic surveillance achieved more true positives than manual ward surveillance for BSI-A (three vs none), CRI1 (eight vs six), CRI2 (nine vs one), and UTI-A (four vs one), whereas manual ward surveillance managed more true positives than electronic surveillance for PN1 (four vs two). For detected types, the number of false positives was equal (one vs one), but manual ward surveillance additionally generated four false positives for non-detected types.

Finally, electronic surveillance reduced personnel time needed for surveillance by nearly 85%. Manual ward surveillance took 82.5 personnel hours, which includes the time spent on preparation, surveillance and analysis of results. The generation and evaluation of the MONI–ICU results took 12.5 personnel hours, which includes a preliminary assessment of all patient results, and the study of fuzzy and fully established infection episodes and their underlying symptoms.

DISCUSSION

We found that electronic surveillance of HCAI is more effective than manual ward surveillance, while requiring fewer personnel resources. The study indicates that manual ward surveillance, even when performed in a prospective manner with a variety of data sources available, remains a challenging task. The study also shows that the greatest challenge for electronic surveillance remains the availability and completeness of electronic patient data.

The main strength of the study is that the reference standard was not based on guidelines agreed to within a single healthcare institution, but guided by HELICS definitions that have been established by an international panel of ICSs, and which are accepted as a standard for ICU-acquired infection surveillance within the European health community. The main weaknesses of the study are the short study period and the low number of ICU-acquired infections. By the involvement of a physician in both the construction of the reference standard and the

Table 2 Effectiveness of manual ward surveillance and electronic surveillance based on the number of detection events

Surveillance method	Total events generated	Sensitivity, % 95% CI	Specificity, % 95% CI	PPV, % 95% CI	NPV, % 95% CI
Manual ward surveillance	108	40 (12/30) (23% to 59%)	94 (73/78) (86% to 98%)	71 (12/17) (44% to 90%)	80 (73/91) (71% to 88%)
Electronic surveillance	106	87 (26/30) (69% to 96%)	99 (75/76) (93% to 100%)	96 (26/27) (81% to 100%)	95 (75/79) (88% to 99%)

NPV, negative predictive value; PPV, positive predictive value.

supervision of manual surveillance, some bias may have been introduced to the reference standard.

Other European hospitals have implemented electronic surveillance and prediction systems for HCAI, but they were based on the definitions established by the Centers for Disease Control and Prevention.[17 18] Furthermore, none of the systems encountered used fuzzy set theory and logic, which could result in a loss of (intermediate) information. We used fuzzy values to determine the time of onset of an infection and in the case of pneumonia, to determine if it was ventilator associated or not.

Multiple studies have assessed the effectiveness of diverse infection surveillance methods.[19 20] The sensitivity of the manual ward surveillance is within the reported range; Emori *et al*[19] reported sensitivities between 30% and 85%, while Glenister *et al*[20] reported sensitivities of 62–65%. Variability in specificity between studies is small; all studies reported specificities to be within 91–100%.

Other studies have already shown that electronic surveillance can improve the effectiveness of HCAI detection. Evans *et al*[21] reported an overall sensitivity of 78%. The main difference between the HELP system and MONI–ICU is the utilization of different data resources, which could be a contributing factor to the increased overall sensitivity of MONI–ICU. In Bouam *et al*[17] an overall sensitivity and specificity of 91% was reported. The difference in the overall sensitivity can be explained by the inclusion of the poor PN1 results in our study.

Currently, the MONI–ICU system routinely supports the Clinical Institute of Hospital Hygiene of the Vienna General Hospital in the detection and epidemiological reporting of ICU-acquired infections. Given the results of this preliminary study, the Clinical Institute of Hospital Hygiene could redistribute its resources to achieve a more effective surveillance and epidemiological reporting of ICU-acquired infections with fewer personnel resources, whereas a more reliable connection with the microbiology laboratory information system could improve the MONI–ICU system. A more extensive study is under way to give more precise indications of the effectiveness of electronic surveillance.

CONCLUSION

We report on a fully automated surveillance system for the detection of ICU-acquired infections, which significantly increased the effectiveness of infection detection while requiring only 15% of the personnel resources needed for manual ward surveillance. The preliminary results indicate an improved performance for all detected ICU-acquired infection types except for pneumonias.

Contributors JSB obtained the data, performed data quality reviews on the reference standard, and performed the statistical analysis. HM and KF performed data preprocessing and data quality reviews, provided feedback on technical aspects, and made critical revisions to the paper. JSB and KPA designed the study and wrote the first draft. AB and WK performed the construction of the reference standard, provided feedback on clinical aspects and made critical revisions to the paper. KPA provided unlimited access to the MONI–ICU system and made critical revisions to the paper. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors reviewed and approved the final paper.

Competing interests KPA is also co-founder, CEO and scientific head of Medexter Healthcare, established to disseminate decision support systems broadly with clinically confirmed usefulness and is currently managing the MONI–ICU service. All other authors report no competing interests.

Ethics approval This study was reviewed and approved by the ethics committee of the Medical University of Vienna.

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