ORIGINAL ARTICLE

Electronic Surveillance for Infectious Disease Trend Analysis following a Quality Improvement Intervention

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OBJECTIVE. Interventions for reducing methicillin-resistant *Staphylococcus aureus* (MRSA) healthcare-associated disease require outcome assessment; this is typically done by manual chart review to determine infection, which can be labor intensive. The purpose of this study was to validate electronic tools for MRSA healthcare-associated infection (HAI) trending that can replace manual medical record review.

DESIGN AND SETTING. This was an observational study comparing manual medical record review with 3 electronic methods: raw culture data from the laboratory information system (LIS) in use by our healthcare organization, LIS data combined with admission-discharge-transfer (ADT) data to determine which cultures were healthcare associated (LIS + ADT), and the CareFusion MedMined Nosocomial Infection Marker (NIM). Each method was used for the same 7-year period from August 2003 through July 2010.

PATIENTS. The data set was from a 3-hospital organization covering 342,492 admissions.

RESULTS. Correlation coefficients for raw LIS, LIS + ADT, and NIM were 0.976, 0.957, and 0.953, respectively, when assessed on an annual basis. Quarterly performance for disease trending was also good, with R^2 values exceeding 0.7 for all methods.

CONCLUSIONS. The electronic tools accurately identified trends in MRSA HAI incidence density when all infections were combined as quarterly or annual data; the performance is excellent when annual assessment is done. These electronic surveillance systems can significantly reduce (93% [in-house-developed program] to more than 99.9999% [commercially available systems]) the personnel resources needed to monitor the impact of a disease control program.

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Active surveillance for detection of methicillin-resistant *Staphylococcus aureus* (MRSA) nasal carriage is a widely debated issue in the US healthcare system and is discussed with interest by the media and the public.[1] Most in health care agree that surveillance is necessary at times to curtail the spread of critical pathogens such as MRSA, but the population to test is controversial.[2] We have had a universal admission surveillance program for nasal MRSA colonization since August 1, 2005.[3] In the first 5 years, it resulted in a net reduction in medical care costs for our organization of $5.4 million[4] and an expected avoidance of 90 deaths.[3,5,6] Extensive examination of patient medical records to substantiate our outcome required considerable time and effort, and we therefore sought to validate simpler ways to assess outcome.

New and improved electronic methods for the detection and tracking of nosocomial infections have been developed recently,[6-12] and these innovative systems might be used to eliminate the laborious aspects of medical record review. The purpose of this investigation was to compare 3 electronic data systems with manual chart review to determine whether any of these systems are a suitable replacement for medical record review for determining trends in clinical disease during a MRSA control program. MRSA was chosen as the model organism because of our extensive data experience with this organism. Our hypotheses were that readily available electronic surveillance systems can reliably replace manual chart review and that using them would save substantial time for infection preventionists. Proving this should help leaders and decision makers at healthcare organizations use their own data in an efficient way to reliably monitor the outcome of key quality assurance and infection control interventions, such as MRSA control.

METHODS

Setting and Study Population

NorthShore University HealthSystem (hereafter, NorthShore) comprises 3 hospitals and a research institute and has ap-

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proximately 800 inpatient beds, 40,000 annual admissions, 75 affiliated offsite offices, 450 staff physicians, and more than 1,000 independent physicians. To date, more than 300,000 patients have been tested on admission, and this report analyzes 2 years of baseline information plus data from the complete first 5 years of the NorthShore MRSA intervention.

Data Collection and Analysis

Three electronic programs were compared with medical record review for the detection of MRSA clinical disease: (1) the Nosocomial Infection Marker (NIM), a proprietary algorithm for detecting healthcare-associated infection (HAI) by means of laboratory information system (LIS) data offered on a subscription basis by CareFusion through its MedMined system; (2) raw positive culture data from the hospital's LIS (SCC Soft Computer); and (3) positive culture data from the LIS joined to electronic medical record–based admission-discharge-transfer (ADT) data to eliminate cultures unconnected to admissions. Table 1 outlines what input was required for each approach. MRSA clinical result data (surveillance tests were excluded) from these 3 data sets were entered into an Excel (Microsoft) database for statistical analysis. Data were collected retrospectively from August 2003 through July 2010. Our goal was to demonstrate that these systems showed similar trend results as manual chart review and thus could save infection preventionists a considerable amount of time; it was not to demonstrate that the electronic systems captured exactly the same events as manual chart review.

NIM. The NIM is a feature of CareFusion's MedMined system, which is a multifunctional, web-based data-mining system providing hospital-specific infection control data to its user. The NIM is a validated surrogate marker for hospital-acquired infections.[9] It is defined by a proprietary algorithm and uses microbiology and ADT data from a hospital's LIS to establish putative HAI. To collect our data, a monthly NIM analysis for MRSA was run independently for each of the 3 hospitals as well as combined for an organization-wide NIM result. Data for blood, urine, respiratory, and wound sources were compiled separately as well as combined. No further interpretation of the generated data as to whether the information represented infection was done.

LIS method. SCC Soft Computer is the LIS utilized by NorthShore. Data in this system contain the result of cultures processed in the clinical microbiology laboratory. Reports for the comparison of electronic surveillance with medical record review were generated by running an epidemiology logbook report in the SoftMic portion of the system with the "nosocomial infection" parameter chosen. Organisms were counted once per hospital stay. Monthly statistics were collected for blood, respiratory, urine, and wounds for each of the 3 hospitals and then combined. Wound culture sources were evaluated manually by viewing the source of the specimen in the test order, and those not likely to be from a surgical site (ie, decubitus, toe, etc) were excluded from the count. Data for urinary tract infections (UTIs) were collected and evaluated in 2 ways to determine whether either would enhance the final result: (1) a positive urine culture with any colony count and (2) only positive cultures with colony counts more than 100,000 colony-forming units (CFUs)/mL (on the assumption that those with higher counts more likely represented a true nosocomial UTI). Again, no further interpretation of the data generated as to whether the information represented infection was done.

LIS + ADT method. Positive cultures were identified using a LIS report, as described above. To reduce non-HAI positive cultures, the data were joined to ADT data from the NorthShore Enterprise Data Warehouse by one of the authors (A.R.) in an Access (Microsoft) database. In the resulting database, several rules were applied to identify putative MRSA HAI: (1) only cultures that occurred more than 2 days after admission and up to 30 days after discharge were included; (2) only a patient's first positive culture in a 30-day period was included; and (3) surveillance respiratory cultures from patients with cystic fibrosis and catheter tip cultures were excluded, owing to their diagnostic ambiguity.

Medical record review. Medical record review was performed for all putative MRSA HAIs that were detected by the LIS + ADT method to build the reference standard for comparison.[3] Infections were determined using an approach that has been described elsewhere.[3] Briefly, a bloodstream infection was indicated by a positive blood culture in the absence of a positive clinical culture from any other site. A respiratory tract infection was indicated by a positive respiratory culture, a compatible (changing) chest radiograph indicating a new or worsening infiltrate, and a decision to treat. A UTI was indicated by a positive urine culture and either a decision to treat or a growth of more than 100,000 CFUs/mL plus at least 50 leukocytes per high-power field. A surgical site infection was in-

TABLE 1. Description of Personnel Input for the Surveillance Methods Used

Surveillance method	Inquiry program report needed	Data review needed	Chart review needed	Outcome analysis needed
NIM	Yes	No	No	Yes
LIS	Yes	Yes	No	Yes
LIS + ADT	Yes	No	No	Yes
Chart review	No	Yes	Yes	Yes

NOTE. ADT, admission-discharge-transfer; LIS, laboratory information system; NIM, CareFusion MedMined Nosocomial Infection Marker.

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dicated by a positive culture from a prior surgical site. This process requires approximately 17 minutes of personnel time per chart review, as we have reported elsewhere.[9]

Time studies. Time studies were performed by each individual collecting the specific data (eg, NIM, LIS, and LIS + ADT methods). They recorded the time required from the start of their interrogation up to the time they were finished with their report-writing request. When multiple inquiries were done, the time for all were totaled and averaged. The time required for chart review was based on a prior publication from our group.[9]

Statistical analysis. Multiple regression analysis with Excel was used to compare the clinical MRSA disease trends described by each of the electronic surveillance methods with the trend determined by manual medical record review. Correlation was evaluated for individual infection types (bloodstream, respiratory, urine, and surgical site), for the aggregate of all infections, and for 3 time intervals (monthly, quarterly, and yearly). A correlation coefficient of 0.70 or higher was considered a desirable level of agreement between an electronic method and medical record review to recommend the electronic method as a tool for automated disease trend analysis.

Ethics Statement

This work was approved by the NorthShore Institutional Review Board.

RESULTS

Trend Analysis

During our period of observation, there were 342,492 admissions and 1,322,716 patient-days. The 1,071 potential MRSA infections (0.3% of admissions) were subjected to manual medical record review (109 bloodstream, 228 respiratory, 170 urinary, and 564 wound infections). The results of yearly, quarterly, and monthly comparison using all combined infection sites are shown in Table 2 and Figures 1–3 (as the incidence density, or infections per 10,000 patient-days). Correlation coefficients (Table 2) varied on the basis of infection site and time interval. Overall, there was good correlation between the electronic surveillance systems and manual medical record review so long as a sufficient length of time (eg, total number of events) was captured that incorporated large-enough numbers of MRSA-infected patients; quarterly performance was satisfactory (correlation coefficients, 0.79–0.93), and annual performance was excellent (correlation coefficients, 0.95–0.98). Consistent with the need for sufficient numbers of data points to be included so as to yield a high correlation with manual review, improved correlation was also seen when all infection sites were combined rather than when each was individually assessed. When comparing annual data collection, LIS, NIM, and LIS + ADT all showed very high correlation results ($R^2 > 0.92$). Results were more variable for month-to-month and quarterly comparison of the data sets (Table 2); as indicated, the R^2 values for quarterly measurements of combined cultures all exceeded 0.7. When individual infection sites were compared with monthly and quarterly data sets, NIM and LIS electronic measures did not perform well (Table 2). However, LIS + ADT consistently showed strong correlations throughout quarterly and monthly analysis, which is not surprising given that the clinical chart review selection was based on this method. There was no difference in performance for the UTI data regardless of whether it was compared using routine reporting (results indicating more than or equal to 1,000 CFUs/mL) or restricting the data to only culture results represented by more than 100,000 CFUs/mL.

TABLE 2. Correlation Coefficients for Data Totals by Culture Type and Monitoring Interval

	NIM	LIS	LIS >100,000	LIS + ADT
1-month data sets				
Blood	0.57	0.46	NA	0.88
Respiratory	0.76	0.76	NA	0.91
Wound	0.37	0.45	NA	0.62
Urine	0.51	0.32	0.36	0.70
Total	0.66	0.75	NA	0.86
1-quarter data sets				
Blood	0.49	0.72	NA	0.92
Respiratory	0.88	0.90	NA	0.95
Wound	0.40	0.42	NA	0.60
Urine	0.53	0.55	0.47	0.83
Total	0.79	0.85	NA	0.93
1-year data sets				
Blood	0.70	0.85	NA	0.95
Respiratory	0.97	0.99	NA	0.99
Wound	0.64	0.74	NA	0.59
Urine	0.81	0.89	0.90	0.87
Total	0.95	0.98	NA	0.96

NOTE. The laboratory information system (LIS) method included urinary tract infection (UTI) as defined by any positive culture colony count, and LIS >100,000 included only UTIs defined by a culture colony count more than 100,000 colony-forming units/mL. ADT, admission-discharge-transfer; NA, not available; NIM, CareFusion MedMined Nosocomial Infection Marker.

Time Analysis

NIM. The NIM required a mean of 66.4 seconds of a medical technologist's time to program the system to gather the information requested. Our prior study estimated that 10 minutes of personnel time (or 2 hours per 10,000 admissions) was required for a comprehensive NIM analysis of all admitted patients.[9]

LIS. LIS took an average of 56.4 seconds of an experienced medical technologist's time to gather the needed information.

LIS + ADT. The nature of the databasing used requires manual LIS queries, data export, and data cleanup (eg, removal of duplicates and assignment of cultures to correct

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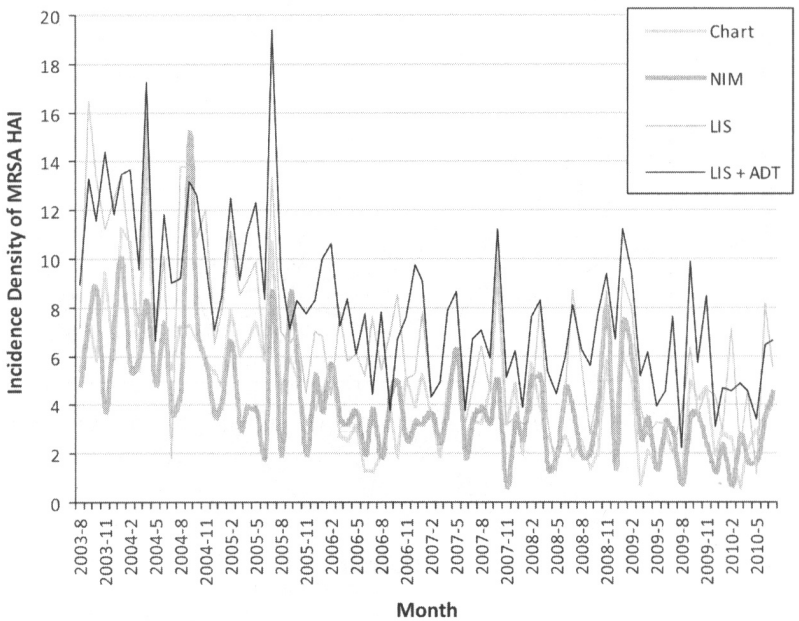

FIGURE 1. Results of monthly comparison using all combined infection sites, depicted as the disease rate per 10,000 patient-days. ADT, admission-discharge-transfer; HAI, healthcare-associated infection; LIS, laboratory information system; MRSA, methicillin-resistant *Staphylococcus aureus*; NIM, CareFusion MedMined Nosocomial Infection Marker.

body categories). This process required approximately 20 hours of a specifically trained operator's time for the total data set in this study.

Manual chart review. Our prior experience found that 17 minutes of personnel (ranging from medical technologist to physician) time was required per medical record,[9] or 38 days for the 1,071 reviews required for a manual chart review in this research investigation; on the basis of our low MRSA disease rate, this equals approximately 1 day for each 10,000 admissions once the potential records for review are identified using the LIS + ADT search.

DISCUSSION

The electronic methods we evaluated appear to be effective as a surrogate for medical record review in determining trends in MRSA HAI incidence density if data are aggregated into periods of 3 months or longer, with 2 of them readily available as commercial systems (NIM and LIS). The quality of the correlation was related to the number of infection events for the observation periods, with the 3-month periods containing at least 9 clinical MRSA infections (median, 18.5 events; range, 9–50 events) and the 1-year periods each having at least 50 clinical infections (median, 69 events; range, 50–155 events; Figures 1–3). Thus, when looking at disease trends following an intervention a sufficient length of time needs to pass after the intervention before evaluating the outcome so that there are enough events to permit a valid analysis using these electronic tools. The time needed will depend on the initial disease burden as well as the size of the hospital population affected by the problem at hand. While all 3 electronic measurements correlated well with disease trends, as can be seen from Figures 1–3, the NIM most closely approximated the actual number of infections determined by medical record review.

Overall, these results support the data published on this topic by Walker et al,[11] who evaluated microbiology cultures over an 8-year period that encompassed more than 2.6 million patient-days. They demonstrated that bacteremic rates of MRSA disease trended very closely with nonbacteremic rates of MRSA isolate recovery based solely on clinical cultures sent to the microbiology laboratory and that using all MRSA clinical isolates allowed for a faster measure to reach statistically significant MRSA rate changes when measuring the impact of an intervention than did monitoring bloodstream infection alone.

Other studies have been done to prove the effectiveness and cost benefit of incorporating electronic systems into hospital-acquired infection surveillance. The common conclusion is that electronic LISs used in conjunction with conventional standards help make detection of nosocomial infections faster, with less personnel time required.[1] However, some suggested that electronic methods are still evolving and need further validation before universal adaptation;[10,12] our goal was to present additional data that indicate that these methods are now sufficiently mature so as to reliably replace manual chart review as an accurate and cost-efficient measurement of infection control intervention impact (eg, trend monitoring) to reduce healthcare-associated disease.

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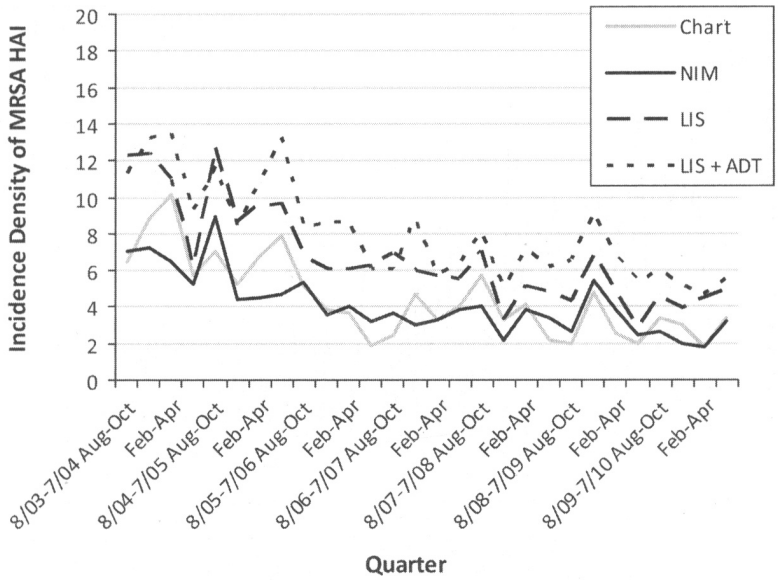

FIGURE 2. Results of quarterly comparison using all combined infection sites, depicted as the disease rate per 10,000 patient-days. ADT, admission-discharge-transfer; HAI, healthcare-associated infection; LIS, laboratory information system; MRSA, methicillin-resistant *Staphylococcus aureus*; NIM, CareFusion MedMined Nosocomial Infection Marker.

A decade ago, Hacek et al[8] compared standard infection preventionist surveillance with 2 computer-based algorithm tracking systems utilizing microbiological data. Their study found that surveillance practices were enhanced significantly when aided by the electronic programs. The conclusion drawn was that electronic methods increased efficiency with little addition to labor, yet further experimentation and improvements must be done before any electronic method was sufficient to become a replacement surveillance tool for enhancing disease detection.

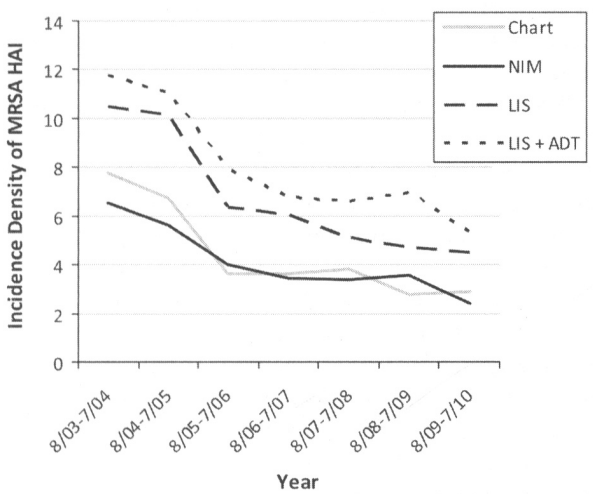

FIGURE 3. Results of yearly comparison using all combined infection sites, depicted as the disease rate per 10,000 patient-days. ADT, admission-discharge-transfer; HAI, healthcare-associated infection; LIS, laboratory information system; MRSA, methicillin-resistant *Staphylococcus aureus*; NIM, CareFusion MedMined Nosocomial Infection Marker.

Leal and Laupland[10] critically reviewed articles that compared electronic methods of detection with standard methods. Their systematic review covered 24 studies encompassing research ranging from use of microbiology data alone or administrative data alone to combining microbiology and administrative data using specifically designed algorithms and concluded that "automated programs reduced surveillance time by up to 61%." However, limitations of electronic surveillance were also detailed, including (1) infections that are diagnosed on the basis of physical symptoms through clinical evaluation or means where positive culture tests are unavailable and (2) cases that would be included where a positive culture does not indicate an infection.

Klompas and Yokoe[12] evaluated electronic surveillance methods of detection for 3 common hospital-acquired infections (central line–associated bloodstream infections, ventilator-associated pneumonia, and surgical site infections) to substantiate that algorithmic analysis (combining microbiology results, diagnosis codes, and antimicrobial dispensing) decreased labor and costs. Each system evaluated produced varying ranges of specificity and sensitivity, causing the authors to conclude that "different algorithms are suitable for different surveillance objectives." There were limitations when translating physical symptoms to diagnosis codes that were then standardized for computer-based algorithms. However, the conclusion remained that electronic surveillance is more time efficient and cost-efficient than historical (medical record review) methods.

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With regard to time analysis, the process time required for the electronic systems to gather the appropriate information was significantly shorter than the 38 days required for a manual chart review in this research investigation. The SCC Soft Computer laboratory program is similar to many widely used microbiology LISs, and it is easily navigable by laboratory personnel and generates rapid results. The time of 56.4 seconds per run is slightly shorter than the NIM program, but not meaningfully so when compared with medical record review. The same findings apply to a manual in-house system (LIS + ADT) if there is sufficient on-site technical expertise available to develop such a program. Therefore, any of the electronic surveillance systems are highly useful surrogates for manual medical record review when trending infection rates after implementation of an infection control program.

There are limitations to our work in that it represents the experience of a single healthcare organization. However, the 3 hospitals included in this research are (1) a major teaching hospital with residency programs and medical students in all the major training disciplines, (2) a hospital where the main training is primarily in family medicine, and (3) a private community facility where no formal resident or medical student training is undertaken. In addition, since our assessment was focused on MRSA we cannot readily generalize the findings to infections caused by other organisms. That being said, on the basis of our presented data, MRSA causes a similar range of disease (except for diarrhea) as do other microbial pathogens in the hospital setting, and there is no biological reason to assume that the electronic surveillance systems would not perform equally well as a surrogate for measuring other infectious disease trends over time. We did not use National Healthcare Safety Network (NHSN) definitions but rather disease descriptions based on our own developed rules. This was done to make the review process as objective as possible and because NHSN definitions are for surveillance activities and do not necessarily reflect clinical diagnosis of disease states. Finally, since relatively long periods of time (eg, somewhat-large data sets) are needed for an acceptable correlation, the methods as used are not necessarily amenable to outbreak detection, but this was not our focus and could not be tested because there were no MRSA disease outbreaks in the study period.

In conclusion, we found that 3 electronic methods for MRSA HAI trending are suitable surrogates for medical record review when used over sufficiently long observational periods; 2 are readily available (NIM and LIS). At our center, annual data analysis with at least 50 MRSA clinical infections per year produced outstanding results, with R^2 values exceeding 0.9 for all electronic methods. Quarterly performance was also good, with R^2 values exceeding 0.7 for all systems; there were at least 9 infections per quarter. All of the electronic systems were very consistent in predicting trends over time—an important observation given that the Centers for Disease Control and Prevention indicates that all healthcare systems need to demonstrate that whatever infection control interventions are being used must reduce multidrug-resistant organisms[2] or else expand their program to tier 2, which includes active surveillance. Any of the 3 electronic systems tested could be a suitable replacement for medical record review to determine clinical case disease trends for MRSA infection in a comprehensive infection control program and provide the opportunity for devoting scarce human resources to other important infection control activities.

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Potential conflicts of interest. All authors report no conflicts of interest relevant to this article. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

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