Development and Evaluation of a Fully Automated Surveillance System for Influenza-Associated Hospitalization at a Multihospital Health System in Northeast Ohio

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Abstract

Background Performing high-quality surveillance for influenza-associated hospitalization (IAH) is challenging, time-consuming, and essential.

Objectives Our objectives were to develop a fully automated surveillance system for laboratory-confirmed IAH at our multihospital health system, to evaluate the performance of the automated system during the 2018 to 2019 influenza season at eight hospitals by comparing its sensitivity and positive predictive value to that of manual surveillance, and to estimate the time and cost savings associated with reliance on the automated surveillance system.

Methods Infection preventionists (IPs) perform manual surveillance for IAH by reviewing laboratory records and making a determination about each result. For automated surveillance, we programmed a query against our Enterprise Data Vault (EDV) for cases of IAH. The EDV query was established as a dynamic data source to feed our data visualization software, automatically updating every 24 hours.

To establish a gold standard of cases of IAH against which to evaluate the performance of manual and automated surveillance systems, we generated a master list of possible IAH by querying four independent information systems. We reviewed medical records and adjudicated whether each possible case represented a true case of IAH.

Results We found 844 true cases of IAH, 577 (68.4%) of which were detected by the manual system and 774 (91.7%) of which were detected by the automated system. The positive predictive values of the manual and automated systems were 89.3 and 88.3%, respectively.

Keywords
- monitoring and surveillance
- public health
- patient records
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- human
- automation

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Relying on the automated surveillance system for IAH resulted in an average recoup of 82 minutes per day for each IP and an estimated system-wide payroll redirection of $32,880 over the four heaviest weeks of influenza activity.
Conclusion Surveillance for IAH can be entirely automated at multihospital health systems, saving time, and money while improving case detection.

Background and Significance

The category of pneumonia and influenza is a top ten leading cause of death in the United States.[1] Each year, influenza infection results in up to 710,000 hospitalizations, 95,000 intensive care unit admissions, and 27,000 deaths nationwide.[2,3] Influenza-associated hospitalization (IAH) is an essential metric for hospital operations and infection prevention activities and, as of 2017, is reportable to public health authorities in at least nine states in the United States, including our state of Ohio.[4] The Ohio Department of Health (ODH) generally defines IAH as a patient with a clinically compatible illness who has a positive influenza test collected within 14 days before or 3 days after admission to an inpatient location of an acute care hospital.[5]

Surveillance for both hospital-associated and community-acquired infections has traditionally been the responsibility of hospitals' departments of infection prevention. Measurement and public reporting of IAH are particularly burdensome for hospital infection preventionists (IPs) during times of high influenza activity. Incomplete reporting of notifiable communicable diseases to public health is a well-established problem.[6–8] While computerized surveillance software and electronic laboratory reporting (ELR) to public health have greatly enhanced surveillance practice over the last several years, the data quality issues associated with person-dependent case finding remain.[9,10]

The Cleveland Clinic is a multinational health system consisting of 11 hospitals and 5 free-standing emergency departments in the state of Ohio in the United States. The major limitation to ELR for IAH at the Cleveland Clinic is the inability to transmit cases involving a positive influenza test result during an emergency department encounter that result in subsequent admission to the hospital. Our ELR messages rely on patient status data at the instant of test result, thus the ELR system cannot detect an emergency department patient who was admitted after an influenza-positive test result. These emergency department patients represent a large proportion of total IAH and have to be reported individually by IPs.

Documentation in the electronic medical record (EMR) recorded as part of routine clinical practice can be successfully leveraged to automate influenza detection.[11,12] Existing literature establishing the superiority of electronic surveillance for influenza has primarily involved syndromic surveillance as opposed to laboratory-confirmed influenza.[13,14] Defining a gold standard against which to assess the performance of a novel surveillance system is challenging. Previous research has described joining data from disparate information systems and medical record review for this purpose.[15,16] Recent research has illustrated the utility of electronic infection surveillance and data visualization for informing decision making.[17]

Objectives

Our objectives were to develop a fully automated surveillance system for laboratory-confirmed IAH in our multihospital health system, to evaluate the performance of the automated system during the 2018 to 2019 influenza season at eight hospitals by comparing its sensitivity and positive predictive value (PPV) to that of the manual surveillance system, and to estimate the time and cost savings associated with reliance on the automated surveillance system.

Methods

Manual Surveillance System

At the Cleveland Clinic health system, IPs at each hospital manually detect and record cases of IAH using commercial surveillance software (TheraDoc, Premier, Inc., Charlotte, North Carolina, United States). During business hours, IPs review all positive influenza tests from hospital and emergency department encounters and, if the patient meets the ODH case definition for IAH, create a Notifiable Disease Document in TheraDoc. The case is then reported to public health in accordance with the State Administrative Code by manually keying required patient data into the State's Web-based Ohio Disease Reporting System (ODRS). All test results for influenza are reviewable in TheraDoc except for one point-of-care molecular test used in the emergency department at one hospital. All hospitals in our health system use TheraDoc, creating a system-wide database for manually recorded IAH. System-wide manual surveillance summaries are generated using the Notifiable Disease Document reporting functionality of TheraDoc.

For this study, 24 IPs at 11 hospitals in our health system were asked the following question by email: "During peak activity, approximately and on average, how many minutes per day do you spend on inpatient influenza surveillance?" In this survey, "peak influenza activity" was not objectively defined.

Automated Surveillance System

All hospitals in our health system use an interoperable EMR (EPIC, Epic Systems Corporation, Verona, Wisconsin, United States) and share a home-grown universal data repository called the Enterprise Data Vault (EDV). We programmed a Teradata (Teradata Corporation, San Diego, California, United States) database to prospectively report cases of IAH from EDV. The health system's Enterprise Analytics Division developed

EDV to make accessible to clinicians and information systems practitioners the clinical and laboratory information recorded in our EMR, as well as International Classification of Diseases - 10th Revision (ICD-10) data.

Our database joined all positive molecular influenza test data to associated hospital and free-standing emergency department encounters. Data fields included influenza test results, and encounter dates and locations, including unit of discharge. The database, automatically updated daily with extracts from EPIC, was set to feed a Tableau (Tableau Software, Seattle, Washington, United States) dashboard that summarized and reported the total number of IAH to hospital stakeholders weekly via email subscription. Cases in this automatic system included all patients with positive influenza tests collected within the first three calendar days of an inpatient or observation hospital encounter or during an emergency encounter that resulted in admission to any of our acute care hospitals.

Surveillance System Comparison

We designed our working definition of a "true case" to closely approximate the ODH case definition for IAH. For this project, a true case was defined as any patient admitted to an inpatient ward of an acute care hospital who had a positive influenza test in the EMR collected within 14 days before or 3 days after admission to an inpatient ward of an acute care hospital.

Patients with a positive influenza test joined to an encounter resulting in discharge from an inpatient hospital ward in EDV were considered true cases, as were patients with a positive influenza test collected during an emergency department encounter resulting in transfer to an acute care hospital. We considered this link in EDV between a positive test and an inpatient ward encounter to be equivalent to a medical record review. One IP performed medical record review of the remaining possible cases to determine whether they met our case definition of IAH (►Fig. 1) and to determine why they were not detected by the automated system.

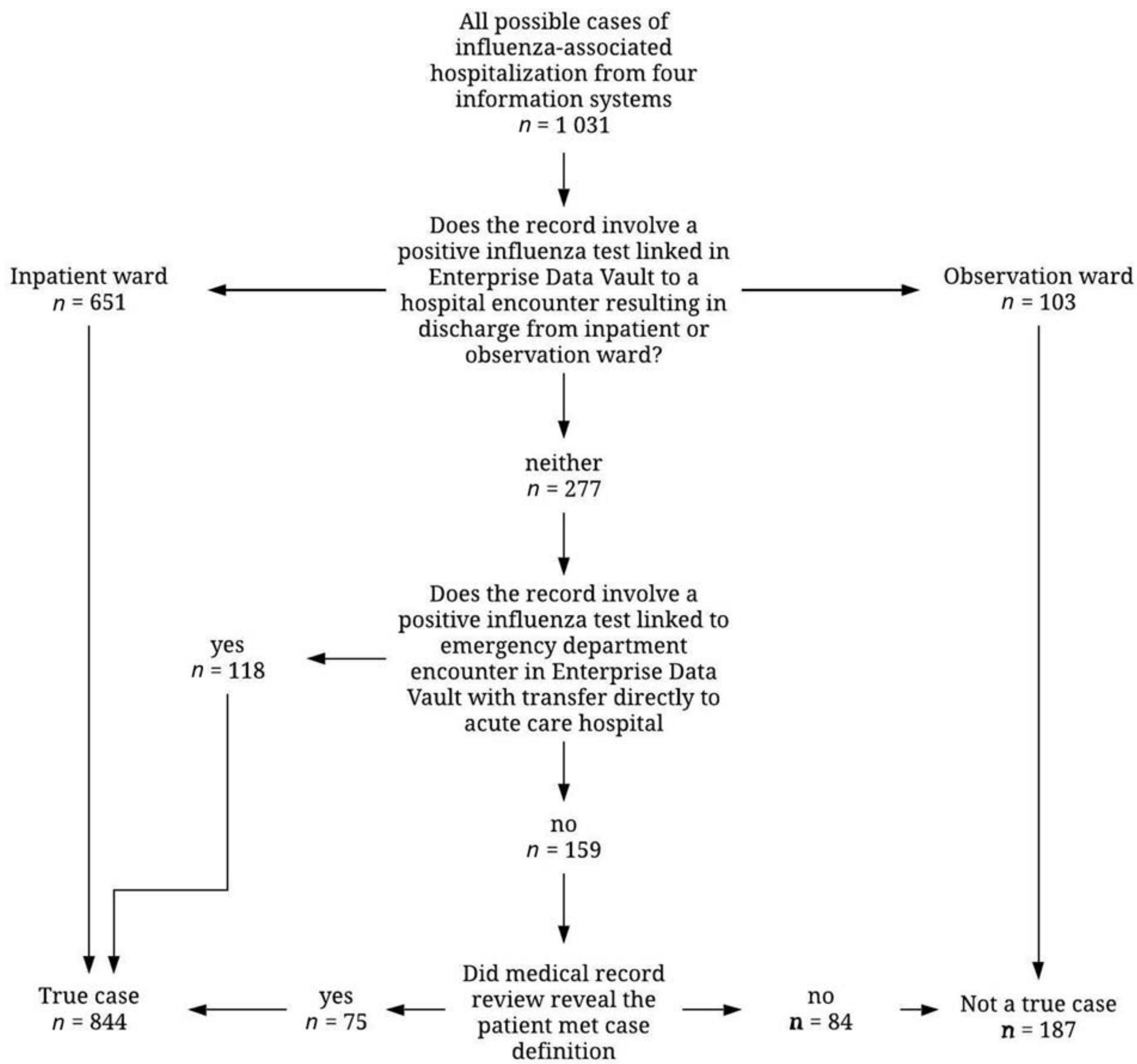

Fig. 1 Process flow for ascertaining whether patients met the definition of a true case of influenza-associated hospitalization.

To establish a gold standard of true cases of IAH against which to assess the performance of the surveillance systems, a list of all possible cases was generated by linking records by patient name and date of hospitalization from four independent information systems. Possible cases included all records of eight of our hospitals between September 1, 2018 and April 15, 2019 in:

- The automatic system (Teradata - EDV query).
- The manual system (TheraDoc) Notifiable Disease Documents for IAH.
- Patients admitted with an influenza-related diagnosis (ICD-10 codes).
- The ODRS IAH reports.

Eight of the 11 hospitals in our health system were selected for this analysis because a list of patients was available from all four databases. IPs at the 3 of the 11 hospitals did not routinely enter cases of IAH directly into ODRS during the study period. Because of the unreliability of IP-entered cases of IAH in ORDS at those three hospitals, we decided to exclude them from our study.

We queried our billing information system independently for a list of patients admitted during the study period with an admission diagnosis related to influenza virus infection. The following ICD-10 codes were included in the query: J09.X1, J10.00, J10.1, J11.00, J11.1, and Z87.09.

IPs at each hospital generated a list of IAHs that they reported to ODRS between September 1, 2018 and April 30, 2019. ODRS data extraction is based on date of report, so cases were excluded if the hospitalization date occurred after April 15, 2019.

Based on guidelines from the United States Centers for Disease Control and Prevention for evaluating the performance of public health surveillance systems,[18] we calculated the sensitivity and PPV of our manual and automated IAH surveillance systems. The sensitivity was calculated as the percent of true cases detected. PPV was the percent of all cases detected by each system that met our case definition for IAH.

Data were joined and managed using SAS Enterprise Guide version 7.15 (SAS Institute, Cary, North Carolina, United States) and Microsoft Excel (Microsoft Corp, Redmond, Washington, United States). The incidence of IAH reported by each surveillance system was calculated using MedCalc for Windows, version 15.0 (MedCalc Software, Ostend, Belgium).

Results

A list of 1,031 distinct patients with possible IAH was generated from the four databases. There were 646 total patients reported by the manual system and 877 total patients reported by the automated system from 8 hospitals (►Table 1). As illustrated in ►Table 1, the percent of cases in each system that were true IAH (PPV) varied between hospitals, but the range of variation was narrower for the manual system compared with the automated system (83–100 vs. 64–100, respectively).

We established 844 true cases of IAH. An admission diagnosis related to influenza infection was present in 688 (82%) true cases. Thirty-five (4%) true cases diagnosed with influenza appeared in none of the three other databases. There were 767 hospitalizations reported to ODRS, of which 690 (90%) were true cases.

The distribution of cases reported in each surveillance system by whether they met the case definition is shown in ►Table 2. Sensitivity and PPV of the manual system was 68.4 and 89.3%, while that of the automated system was 91.7 and 88.3%. The cumulative incidence of true IAH was 1.03 per 100 admissions by the automated system and was 0.76 per 100 admissions by the manual system (rate ratio: 1.34, 95% confidence interval: 1.20–1.49).

From the 10 IPs who responded to our inquiry (survey response rate: 42%), we calculated an average of 82 minutes

Table 1 Number of patients detected by two surveillance systems for IAH that did (true case) and did not (not true case) meet our case definition for IAH and PPV, eight hospitals, September 1, 2018 to April 15, 2019

	Automated system			Manual system		
	True cases *N* (%)	Not true cases *N* (%)	Total	True cases *N* (%)	Not true cases *N* (%)	Total
Hospital 1	70 (64)	39 (36)	109	57 (86)	9 (14)	66
Hospital 2	73 (87)	11 (13)	84	69 (84)	13 (16)	82
Hospital 3	172 (86)	29 (14)	201	121 (83)	25 (17)	146
Hospital 4	41 (100)	0 (0)	41	42 (91)	4 (9)	46
Hospital 5	173 (100)	0 (0)	173	133 (97)	4 (3)	137
Hospital 6	97 (92)	8 (8)	105	103 (89)	13 (11)	116
Hospital 7	86 (98)	2 (2)	88	5 (100)	0 (0)	5
Hospital 8	62 (82)	14 (18)	76	47 (98)	1 (2)	48
Total	774 (88)	103 (12)	877	577 (89)	69 (11)	646
PPV	88.3%			89.3%		

Abbreviations: IAH, influenza-associated hospitalization; PPV, positive predictive value.

Table 2 Number of patients in two surveillance systems that did and did not meet the case definition of influenza-associated hospitalization, eight hospitals, September 1, 2018 to April 15, 2019

	True case *N* (%)	Not a true case *N*
Detected by automated system	774 (92)	103
Not detected by automated system	70 (8)	74,496
Automated system sensitivity	91.7%	
Detected by manual system	577 (68)	69
Not detected by manual system	267 (32)	74,530
Manual system sensitivity	68.4%	

per day per IP is spent on manual IAH surveillance and reporting during peak influenza activity (range: 30–180 minutes).

Discussion

We successfully developed and implemented a fully automated, highly sensitive surveillance system for IAH that detected significantly more true cases of IAH than were recorded manually. As illustrated in ►Table 1, the proportion of manually recorded cases that are true IAH varies between hospitals in our health care system. Centralized surveillance leveraging documentation in the EMR, as has been described for device-associated infection denominators,[19] frees IP time, is reliable, and reduces interhospital variability in case detection. Our findings are consistent with others that have found that technological solutions for influenza surveillance may outperform manual methods. Automated surveillance systems developed at one health care system can potentially be replicated at other institutions.[20,21] With the vast majority of acute care hospitals having now adopted EMRs,[22] replication of this database development at other health care systems is feasible.

Of the true cases not detected by the automatic system, 58 (83%) were patients who had a positive test collected at an outpatient visit, were sent home, and were later admitted within 14 days. It is quite possible that some of these 58 patients were admitted for issues not related to influenza infection, therefore did not meet the actual ODH case definition. Nine (13%) influenza test results did not appear discretely in the EMR. Six of those nine patients had positive point-of-care rapid influenza antigen tests that are no longer in use within our health care system and have been replaced by molecular influenza tests. Our Teradata query searched for the word “positive” in the test result component. Because the point-of-care rapid tests did not contain the word “positive” in the result component, our system did not detect them. That these missing tests are no longer in use carries implications for the future performance of the surveillance system. By replacing missing tests with the molecular tests that were detected, we can anticipate that the sensitivity and PPV of the automated system will be improved after our study period.

We cannot be certain that additional true cases of IAH did not remain hidden from our effort to establish a master list of all possible cases, resulting in an overestimation of the sensitivities of both systems. For instance, we would not have detected a patient with a positive influenza test during an outpatient encounter who was later admitted and discharged from a hospital outside of normal business hours and did not have an influenza-related diagnosis. In this study, only 13 (2%) true cases missed by the automatic system lacked a diagnosis of influenza, so the prevalence of still-hidden cases is likely low.

Limitations to relying on computerized surveillance are extract intervals and technical downtime. Our database extracts from the EMR at 24-hour intervals, so during normal operation, there is a maximum delay of 24 hours before IAH cases are reported. If the database fails to update at the normal interval, reporting of cases through the dashboard might be delayed further. However, the computerized component of manual surveillance subjects it to this same limitation. The sum of these limitations to fully automated surveillance for IAH is no greater than the issues of reliability associated with person-dependent case finding and record creation.

Cost Savings

The majority of IP time spent related to IAH surveillance now involves manually keying patient data into ODRS. Historically, each of the 30 IPs in our health system was responsible for keying reportable IAH into ODRS. Automated IAH database development enabled us to centralize the clerical task of reporting IAH to public health to a single individual. With an average of 82 IP minutes per day saved during the 4 weeks of peak influenza activity, this project resulted in an estimated infection prevention payroll redirection of $32,880 through those four intensive weeks of case reporting. With the adoption of automated surveillance for IAH, IP time can be redirected to more clinically meaningful activities during a time of the year when in-person consultation is particularly important.

Conclusion

Surveillance for high-volume infections requiring low cognitive effort, such as IAH, can be entirely automated with greater sensitivity than is practical through manual surveillance. Elimination of interrater variability, a lodestar of public health surveillance, can be achieved by removing the limitations inherent to person-dependent case finding and reporting.

Clinical Relevance Statement

While accurate and timely surveillance for IAH provides essential intelligence for hospital operations, it may also inform clinical practice decisions including those related to empiric antiviral treatment and chemoprophylaxis. Leveraging technology to improve the efficiency and accuracy of surveillance for IAH has the potential to impact lives by informing risk as it relates to infectious disease activity. Unburdening infection preventionists from clerical tasks frees up their time for more valuable patient care activities.

Multiple Choice Questions

1. How did the authors describe the performance of their automated surveillance system for influenza-associated hospitalization relative to manual surveillance?

a. Higher sensitivity.
b. Lower sensitivity.
c. No difference in sensitivity.
d. Unable to evaluate the performance.

Correct Answer: The correct answer is choice a. The authors calculated the sensitivity of their automated system to be 91.7% while that of the manual system was 68.4%.

2. Which of the following sources of information were used to create a master list of cases of IAH against which to assess the performance of the surveillance systems?

a. Emergency room roster of patients with influenza.
b. Patients hospitalized with ICD-10 codes related to influenza.
c. School absenteeism reports.
d. Health department reports of influenza-like illness.

Correct Answer: The correct answer is b. True cases of IAH were ascertained by reviewing the medical records of patients in the automated surveillance system, the manual surveillance system, the Department of Health Disease Reporting System, and a list of patients with ICD-10 codes related to influenza virus infection.

Protection of Human and Animal Subjects

Our health care system Institutional Review Board exempted this project from full review, considering it minimal risk research involving secondary data collected as part of normal health care operations.

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None.

Conflict of Interest

None declared.

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