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Integrating Clinical Practice and Public Health Surveillance Using Electronic Medical Record Systems

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Abstract: Electronic medical record (EMR) systems have rich potential to improve integration between primary care and the public health system at the point of care. EMRs make it possible for clinicians to contribute timely, clinically detailed surveillance data to public health practitioners without changing their existing workflows or incurring extra work. New surveillance systems can extract raw data from providers' EMRs, analyze them for conditions of public health interest, and automatically communicate results to health departments. The current paper describes a model EMR-based public health surveillance platform called Electronic Medical Record Support for Public Health (ESP). The ESP platform provides live, automated surveillance for notifiable diseases, influenza-like illness, and diabetes prevalence, care, and complications. Results are automatically transmitted to state health departments.
(Am J Prev Med 2012;42(6S2):S154–S162) © 2012 Elsevier Inc

Electronic medical record systems are transforming primary care. EMRs are being used to increase the safety, quality, and efficiency of routine practice by consolidating patients' clinical data for rapid retrieval, applying clinical decision support to check for allergies and drug interactions, and facilitating electronic prescribing.[1] In parallel to these clinical goals, EMRs have rich potential to improve integration between primary care and public health practice. Emerging surveillance systems can automatically scan the data that clinicians routinely record in EMRs in the course of clinical care. Findings of public health importance are electronically transmitted to health departments. Recent legislation is creating increasingly strong incentives for clinicians and EMR vendors to participate in electronic public health reporting.[2,3] The current paper describes the Electronic Medical Record Support for Public Health (ESP) surveillance platform, a model system that leverages EMR data to seamlessly exchange information between providers and public health departments. Current applications include notifiable disease case reporting, influenza-like-illness syndromic surveillance, and automated monitoring of diabetes risk factors, prevalence, care, and complications. ESP systems are currently operational in Massachusetts and Ohio.

The ESP platform consists of software that loads EMR data extracted from clinicians' proprietary systems, analyzes these data for events of public health interest, and electronically communicates findings to public health agencies.[4] The ESP platform's surveillance modules automatically execute complex disease-detection algorithms to provide meaningful surveillance without requiring clinicians to manually parse potential cases. This helps remove providers' primary impediment to public health reporting, namely the substantial effort needed to sift through raw data, document clinical impressions, and assemble reports. By reliably automating clinical analyses for selected outcomes, the ESP surveillance platform shifts the burden of reporting from clinicians to information systems.

Automated EMR-based surveillance can substantially increase the quantity, breadth, and timeliness of data available to health departments. EMR-based surveillance is not only more timely and complete compared with conventional reporting but also makes it possible to routinely monitor health indicators (such as BMI, blood pressure, and serum cholesterol values) and processes of care (such as treatments

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0749-3797/$36.00
http://dx.doi.org/10.1016/j.amepre.2012.04.005

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for infectious diseases, nutrition counseling for diabetes, and medications for patients with chronic diseases) that are difficult or impossible to track with traditional surveillance methods. Tracking these indicators in real time can help inform the development and assessment of targeted interventions such as outbreak responses or health screening campaigns. In addition, the size of many EMR populations facilitates meaningful surveillance for rare diseases (e.g., type 2 diabetes in children), minority groups, and isolated populations that can be difficult to monitor with survey methods.

The ESP surveillance platform was created by the Harvard Center of Excellence in Public Health Informatics in collaboration with the Massachusetts Department of Public Health. The project was funded by the CDC. The ESP platform consists of distinct modules for data acquisition, analysis, and reporting. This helps facilitate compatibility with different EMR systems and different receiving agencies as well as simplifying the integration of new surveillance targets over time.[5] All ESP system code is freely available under an open-source Library General Public License[6] from esphealth.org.

Architecture

The ESP surveillance platform takes comprehensive electronic extracts of every patient encounter every 24 hours from the source practice's EMR. These extracts are arrayed within ESP into separate database tables for patient demographics, vital signs, diagnosis codes, test orders, test results, medication prescriptions, allergies, social history, and provider contact details. Proprietary local codes are mapped to uniform concepts ("heuristics") and universal codes as needed to support case detection. The ESP system searches these tables and concepts for relevant events whenever the tables are updated. Target events are packaged into individually identifiable case reports or aggregated together for population-level summaries, depending on the surveillance target, for secure electronic transmission to the state health department. Data security is assured by running the ESP software behind the host practice's firewall so that proprietary and privileged patient data remain under the host practice's ownership and control at all times.

Disease-Detection Algorithms

Sensitive and specific disease-detection algorithms are critical to the success of the ESP platform. Examples of ESP's algorithms are presented in Table 1. The algorithms are designed to reflect physicians' clinical impressions as revealed through their coding, testing, and prescribing choices. They aim to overcome the limited accuracy of diagnosis codes by considering the full array of structured data present in EMRs including present and prior diagnoses, laboratory orders, laboratory test results, and prescriptions. For example, an ICD-9[11] code for tuberculosis in isolation could indicate active, latent, or treated infection or even just possible exposure. A concurrent prescription for antituberculous medications, however, clearly indicates that the patient's clinician suspects active disease.[8]

Likewise, positive hepatitis C antibody tests reported to health departments by laboratories or clinicians are typically classified as chronic or resolved infection. If, however, the EMR has a record of a negative hepatitis C antibody test a few months prior to the current positive test and no previous positive tests or treatments, then it is not a chronic case but an acute one. Integrated algorithms allow the ESP platform to make these important distinctions as well as find nuanced conditions that do not have reliable diagnosis codes or laboratory tests such as culture-negative tuberculosis, postherpetic neuralgia, acute hepatitis B, or type 1 versus type 2 diabetes.[7–10]

Notifiable Disease Reporting

Notifiable disease reporting has traditionally been a practice better honored in the breach than the observance by frontline practitioners. Clinicians tend to under-report because of lack of time and resources for reporting as well as limited knowledge of what, when, and how to report cases.[12,13] The ESP platform helps primary care providers fulfill their statutory reporting obligation by shifting the onus for reporting from manual to electronic systems. The ESP system differs from electronic laboratory reporting systems insofar as it leverages additional EMR data to define events rather than simply reporting undifferentiated positive test results alone.

For example, ESP's algorithms distinguish acute from chronic viral hepatitis and active from latent tuberculosis.[7,8,14] The algorithms also seek patients with purely clinical diagnoses without supporting laboratory tests such as culture-negative tuberculosis, early Lyme disease, and early syphilis. Likewise, case reports generated by the ESP system include important corollary data absent from electronic laboratory reports such as detailed contact information, pregnancy status, and prescribed treatments.[4] The reports do not, however, include some important risk and exposure data such as food-handler status, intravenous drug use, or recent travel since these data are typically not recorded in EMRs or are present only as free-text entries that are not readily amenable to electronic analysis.

The ESP surveillance platform currently has case-detection algorithms for chlamydia; gonorrhea; pelvic inflammatory disease; acute hepatitis A, B, and C; syphilis; active tuberculosis; Lyme disease; pertussis; and giardiasis. Example algorithms are presented in Table 1. Total cases reported to date and validation data on

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Table 1. Examples of the Electronic Medical Record Support for Public Health's case-detection algorithms

Condition and algorithm accuracy	Algorithm
Acute hepatitis B[7] Sensitivity: 97% Positive predictive value: 97%	ALT>5x normal OR AST>5x normal OR ICD-9 782.4 (jaundice) AND Hepatitis B Core IgM antibody reactive within a 14-d period OR ALT>5x normal OR AST>5x normal OR ICD-9 782.4 (jaundice) AND Total bilirubin>1.5 AND Hepatitis B surface antigen reactive OR hepatitis B viral DNA detected within a 21-day period AND No prior positive results for hepatitis B surface antigen OR hepatitis B viral DNA ever AND No ICD-9 070.32 (chronic hepatitis B) at this encounter or any time in the past OR Seroconversion from hepatitis B surface antigen negative to positive within a 1-year period AND No prior positive results for hepatitis B surface antigen OR hepatitis B viral DNA ever AND No ICD-9 070.32 (chronic hepatitis B) at this encounter or any time in the past
Active TB[8] Sensitivity: 100% Positive predictive value for physician-suspected active TB: 91% Positive predictive value for confirmed active TB: 64%	Prescription for pyrazinamide OR Order for an AFB smear or culture AND ICD-9 010.00–018.99 within the previous 14 days or following 60 days OR Prescription for ≥2 anti-TB medications other than pyrazinamide AND ICD-9 010.00–018.99 within a 60-day period
Type 1 diabetes[10] Sensitivity: 86% Positive predictive value: 89%	Evidence of diabetes (elevated hemoglobin A1C, fasting glucose, prescription for insulin outside of pregnancy, ICD-9 250.xx on two or more occasions, or prescription for a hypoglycemic medication other than metformin) AND One or more of the following: C-peptide assay negative Diabetes auto-antibody assay positive Prescription for urine acetone test strips Ratio of type 1: type 2 diabetes ICD-9 codes >0.5 AND never on an oral hypoglycemic other than metformin Ratio of type 1: type 2 diabetes ICD-9 codes >0.5 AND prescription for glucagon

AFB, acid fast bacteria; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TB, tuberculosis

disease-detection algorithms are shown in Table 2. Concurrent comparisons of the ESP system and conventional reporting show that the ESP platform significantly increases the number, accuracy, completeness, and timeliness of case reports.[4,7,8,14,15] Over the past 5 years, over 12,500 case reports have been submitted by ESP installations to the Massachusetts and Ohio state health departments.

Syndromic Surveillance

The ESP platform includes a module that lets primary care practices serve as sentinel surveillance sites for influenza-like illness. Influenza-like illness reporting is a key component of the national influenza surveillance strategy. As with notifiable disease reporting, the ESP platform lets providers contribute data to public health without the disruption or cost of having to manually collect, process, and send data. The ESP system automatically applies an electronic definition for influenza-like illness to all patient visits each week. The definition, developed for the National Bioterrorism Syndromic Surveillance Demonstration Program, is based on ICD-9 diagnosis codes and vital signs.[16–18] The ESP platform then calculates the proportion of patient visits attribut-

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Table 2. ESP case reporting in Massachusetts and Ohio, June 2006–July 2011

Condition	Validation period, month/year range	During validation period: Cases flagged by ESP platform, *n*	During validation period: Confirmed reportable cases,[a] *n* (%)	During validation period: Confirmed true positive cases,[b] *n* (%)	Total cases reported by ESP,[c] *n*
Chlamydia	6/2006–7/2007	758	758 (100)	758 (100)	10,406
Gonorrhea	6/2006–7/2007	95	95 (100)	95 (100)	2056
Pelvic inflammatory disease	6/2006–7/2007	20	20 (100)	20 (100)	122
Acute hepatitis A	6/2006–12/2009	13	13 (100)	8 (62)	21
Acute hepatitis B	6/2006–1/2010	19	19 (100)	17 (89)	56
Acute hepatitis C	6/2006–5/2008	15	15 (100)	15 (100)	74
Tuberculosis	6/2006–1/2010	26	25 (100)	16 (64)	168
Syphilis	6/2006–5/2008	59	59 (100)	59 (100)	313

Note: Validation findings are from Atrius Health alone. Total cases include cases from both Atrius Health and MetroHealth.
[a]Reportable cases are defined as physician suspicion of disease. ESP algorithms are designed to report cases as soon as clinically suspected rather than waiting for definitive confirmation. This mirrors clinicians' statutory obligation to report as soon as they suspect disease. This policy helps facilitate timely public health responses to emerging threats.
[b]Confirmed cases defined per CDC criteria
[c]From June 2006 to July 2011
ESP, Electronic Medical Record Support for Public Health

able to influenza-like illness each week (Figure 1). Results are stratified by age group and medical practice, and aggregate summaries are sent to the Massachusetts Department of Public Health. These reports are then incorporated into the U.S. National Influenza-Like Illness Surveillance Network each week (www.cdc.gov/flu/weekly). The ESP platform is the largest contributor to Massachusetts' sentinel surveillance network for influenza-like illness, affirming the efficiency of automated EMR-based surveillance compared with manual alternatives.

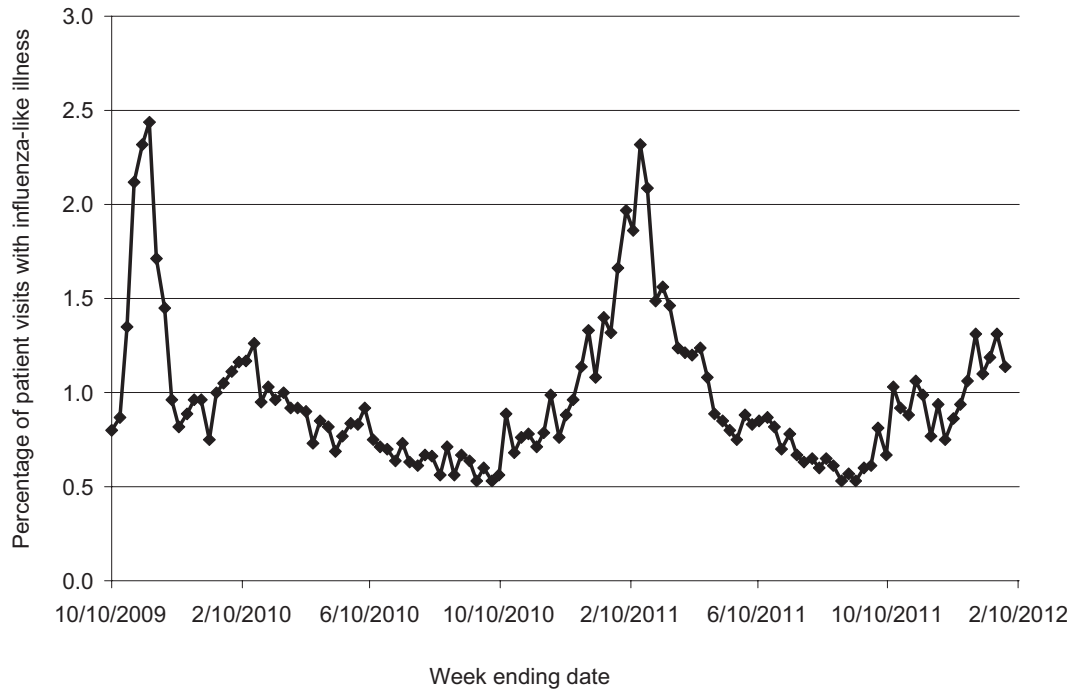


Figure 1. Percentage of ambulatory patient visits fulfilling the CDC syndromic surveillance definition for influenza-like illness: Atrius Health, October 2009–February 2012

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Diabetes Surveillance

The ESP surveillance platform enables primary care providers to contribute diabetes surveillance data without the need to hand-build registries or manually query information systems. The platform has detection algorithms for prediabetes, gestational diabetes, type 1 diabetes, and type 2 diabetes. These algorithms integrate diagnosis codes, laboratory tests, and prescriptions to increase the sensitivity and granularity of surveillance. For example, the ESP algorithm for gestational diabetes looks not only for patients who have positive oral glucose tolerance tests but also pregnant patients with new prescriptions for lancets and test strips. This enhanced case-finding strategy increases case detection by approximately one third.[19] These additional cases are patients who were tested outside the primary care practice (for example, at an obstetrician's office) or who were diagnosed in clinically reasonable but atypical ways (for example, patients with near abnormal oral glucose tolerance test results). Likewise, the ESP platform has an algorithm that distinguishes type 1 from type 2 diabetes by flagging patients with supportive laboratory test results (C-peptide and diabetes auto-antibodies), prescriptions (urine acetone test strips or glucagon), or a plurality of type 1 diabetes diagnosis codes (Table 1).[10]

Surveillance results are automatically collated at the practice level and uploaded to a secure web interface ("The RiskScape") for presentation to clinicians and health department personnel. The RiskScape includes demographic data such as age, gender, race/ethnicity and locality; health indicators such as BMI, blood pressure, serum lipids, and hemoglobin HbA1Cs; and descriptions of care such as medication prescriptions, referrals to nutrition therapy, influenza vaccination status, and postpartum testing for overt diabetes after an episode of gestational diabetes. The RiskScape automatically maps outcomes by ZIP codes and stratifies them by age, gender, race/ethnicity, BMI, and blood pressure (Figure 2). Users can then specify additional filters or stratifications to focus on particular outcomes or populations of interest. For example, a user interested in practice improvement might assess the frequency of referrals for medical nutrition counseling stratified by race and locality. Another user interested in health outcomes might focus instead on the proportion of women with gestational diabetes who are found to have frank diabetes on postpartum testing.

Discussion

The Challenge of Algorithm Maintenance

The ESP platform's algorithms detect cases by searching for laboratory tests, prescriptions, and diagnosis codes that in combination are suggestive of target conditions. The algorithms therefore need to be updated when new tests are introduced, new coding systems are implemented (e.g., ICD-10), and when clinicians change the way they manage target conditions. For example, one criterion in the ESP algorithm for active tuberculosis is "an *ICD-9* code for tuberculosis and prescription for two or more anti-tuberculosis medications other than pyrazinamide." The CDC recently updated their recommendations for the management of latent tuberculosis to include weekly prescriptions for rifapentine and isoniazid.[20] This recommendation may now lead the ESP algorithm to incorrectly flag more cases of latent tuberculosis rather than active tuberculosis if clinicians inappropriately assign patients an ICD-9 code for active tuberculosis rather than latent tuberculosis. The ESP algorithm therefore needs to be modified with a special exception for weekly prescriptions for rifapentine and the updated algorithm needs to be revalidated using current practice data.

Very few practices have the interest, expertise, patient volume, or information technology resources to discern, design, implement, and validate disease-detection algorithm modifications of this nature. There is consequently a pressing need to develop a national public health strategy for development, periodic review, modification, validation, and dissemination of electronic case-detection rules. The authors believe that the CDC and the Council of State and Territorial Epidemiologists are the two organizations best positioned to undertake this responsibility much as they currently maintain and disseminate conventional surveillance definitions for notifiable diseases.[21] Centralizing algorithm maintenance and dissemination will not only be more efficient but also will help assure the uniformity and comparability of EMR-based surveillance data derived from different jurisdictions.

Current Status

Electronic Medical Record Support for Public Health systems are currently operating in Atrius Health in Massachusetts and MetroHealth in Ohio. Atrius Health is a multiprovider, multispecialty ambulatory provider system serving over 700,000 patients. MetroHealth is a mixed inpatient and ambulatory provider group with over 350,000 patients. Additional ESP platform installations are underway in a rural regional health information exchange and two social safety network providers.

Future Directions

The authors are now building a distributed surveillance network called MDPHnet with support from the Office of the National Coordinator for Health Information Technology. MDPHnet is a collaboration between the Massachusetts eHealth Institute, the Massachusetts Depart-

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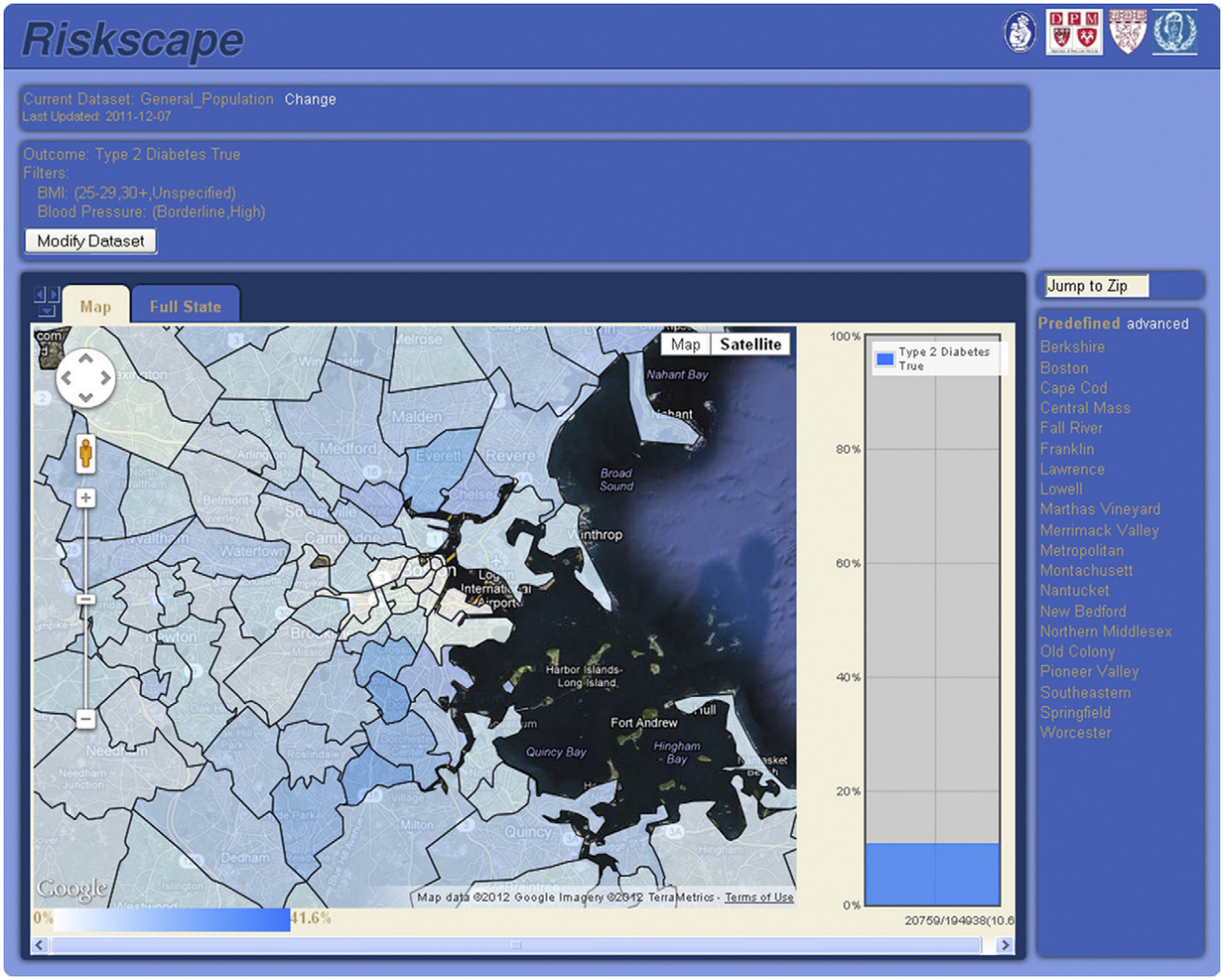


Figure 2. RiskScape screenshot displaying the prevalence of type 2 diabetes by ZIP code among overweight individuals with borderline or elevated blood pressure. The RiskScape web interface permits users to select surveillance outcomes, map results by ZIP code, stratify results by age, race/ethnicity, and gender, and compare disease prevalence by region.

ment of Public Health, the Harvard Center of Excellence in Public Health Informatics, and the Massachusetts League of Community Health Centers. It will create a distributed data network that will enable practices with ESP platform installations to permit designated health department personnel to query participating practices' EMR data through menu-driven and ad hoc queries. Practices will have the option to review all queries before they are executed, to review the results before returning them to the requester, or both. This model will allow practices to make their data available for public health purposes without relinquishing control over them.[22,23] The ESP platform lends itself to providing a consolidated picture of health and running distributed custom queries because data are arrayed in a common data model in all sites, and key laboratory tests are mapped to common concepts that facilitate comparability among institutions.

The authors also hope to build capacity for public health agencies to communicate recommendations back to clinicians via the ESP platform. This could be useful to alert providers to emerging infectious disease outbreaks in their communities, to elicit further information about reported cases, to encourage preventative interventions for patients at particular risk, and to help providers compare their populations and care patterns to similar providers elsewhere. Public health applications could also provide point-of-care clinical decision support around issues such as antibiotic prescribing, immunization requirements, and blood pressure or lipid-control goals.

Limitations

There are important limitations to what can be expected of EMR-based surveillance systems. EMRs can only re-

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port cases if they have sufficient electronic data on hand to meet the electronic case definition. If patients fragment their care between multiple providers with different EMR systems (for example, their primary care physician and a local hospital) then no single EMR system may have sufficient data to detect the case. Likewise, clinicians differ in their workup, management, and coding of target conditions. The ESP platform's algorithms attempt to mitigate incomplete data and heterogeneity in clinical practice by stipulating multiple criteria for each target condition to increase the likelihood of case detection (Table 1). This strategy does improve case detection, but patterns of care (such as current medications, most recent blood pressure or BMI, and key referrals) will still be under-reported for patients that get care from multiple providers with unconnected EMRs.

Further, the ESP system's case reports do not include important contextual data such as dietary habits, exercise, smoking, animal exposures, incarceration, street drug use, or recent travel. These data elements are variably documented by clinicians and typically only recorded as free-text rather than structured data. Natural-language processing techniques may improve capacity to report these risks in the future, and some EMRs are moving to capture these data more consistently (e.g., smoking status). For the present, EMR-based surveillance systems can speed epidemiologic investigations through early notification and provision of detailed contact information, but they are unlikely to replace conventional investigative methods for critical risk factors and exposures.

The initial installation and activation of the ESP surveillance platform can be complicated and expensive. Clinical practices that wish to install the ESP platform need to invest in a server to host ESP (estimated cost approximately $5000) and programming expertise to get their EMR to generate daily extracts to populate the ESP system. The latter is not particularly complicated but does require short-term expert effort. Practices also need to map laboratory tests relevant to ESP's case-detection algorithms from the local proprietary codes used by their EMR systems into the heuristic concepts that the ESP system uses for case detection (e.g., "hepatitis B DNA test" or "fasting blood glucose") as well as to specialized nomenclatures required by health departments (e.g., logical observation identifier names and codes). The ESP platform does include tools to identify which native tests need to be mapped, but mapping does require some familiarity with laboratory nomenclature and test types. Knowledgeable clinicians typically require a few hours to complete this mapping.

Finally, once the ESP system has been populated and relevant tests have been mapped, practices need to validate the process by reviewing a selection of cases detected by the ESP system as a safety check on the integrity of its data feed, mapping, and case-identification algorithms. The time and effort required to complete this process vary widely depending on the quality of practices' existing records of reportable cases and the availability of clinical staff to review cases flagged by the ESP system for accuracy. Once installed and validated, the ESP platform typically runs automatically thereafter with minimal need for maintenance and support from the host practice. The greatest ongoing requirement is to update laboratory test mappings when relevant new tests are introduced into the practice (typically, a rare occurrence).

Purchasing a server and funding a programmer to initiate an ESP system probably puts the platform beyond the financial and technical resources of most solo practitioners or small group practices. A single ESP server, however, is capable of serving hundreds of physicians and millions of patients. The required investment is therefore more reasonable for large group practices or health information exchanges, particularly because these organizations tend to already have information technology support staff. Health information exchanges are particularly attractive sites for installing ESP systems because their role in integrating data from all providers in a community mitigates the risk of misclassifying cases due to incomplete data when patients receive care from multiple providers with different EMRs.

Alternatively or additionally, the Office of the National Coordinator for Health Information Technology's "Meaningful Use" criteria could encourage EMR providers to integrate an ESP data interface directly into EMR software packages or ESP could be configured as a cloud-based service thereby saving practices the effort and complexity of a custom ESP platform installation. Meaningful-use criteria do require EMRs to participate in public health reporting.[2] The initial public health goals of the meaningful-use process are limited to electronic laboratory reporting, syndromic surveillance, and immunization registries. Later stages, however, may require notifiable disease-case reporting.

Finally, health departments need appropriate electronic infrastructure to receive EMR-based reports. The meaningful-use legislation unfortunately did not provide resources to health departments to fund new infrastructure to receive EMR reports.[3] The Massachusetts Department of Public Health and the Ohio Health Department overcame this challenge by using their existing electronic laboratory report receivers to accept reports from ESP systems. Almost all states are currently capable of receiving electronic laboratory reports; 15% report they are also currently capable of receiving EMR-based reports.[24] Both the Massachusetts and Ohio health departments have successfully

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integrated reports from ESP systems into their existing case management systems. Nonetheless, financial constraints substantially delayed the integration of ESP data into the Massachusetts health department's case management system and have hindered the Ohio health department's capacity to accept the full range of data that the ESP platform is capable of including in case reports.

Conclusion

The ESP surveillance platform serves as a useful model for how EMRs can enable primary care providers to engage with public health departments without complicating existing workflows or incurring extra work. The ESP platform enables clinicians to provide high-quality surveillance data on notifiable diseases, influenza-like illness, and diabetes to public health agencies. EMR-based surveillance helps health departments acquire rich and timely data on broader populations and wider sets of health indicators than is routinely possible with current surveillance systems.

Meaningful-use legislation has dramatically increased the incentives for providers to implement EMR systems and for EMR vendors to develop public health surveillance modules for their systems. Current meaningful-use criteria only include relatively basic public health reporting requirements (electronic laboratory reporting, immunization registries, and syndromic surveillance), but there is rich potential to build on this foundation to take advantage of the wealth of data routinely captured by EMRs. Doing so could dramatically improve the quantity, quality, and granularity of surveillance data available to health departments. In addition, EMRs may be a means for health departments to communicate data and recommendations directly back to providers at the point of care. Doing so will help complete a virtuous circle connecting primary care and public health through EMRs.

Publication of this article was supported by the U.S. DHHS Health Resources and Services Administration (HRSA) and the NIH National Institute on Minority Health and Health Disparities.

Funding for this work was provided by the CDC (grant 1P01HK00088) and the Office of the National Coordinator for Health Information Technology (contract 90HT0038/01).

The authors wish to thank Julie Dunn, MPH, and Michael Murphy, BS, for their dedicated support of the ESP project.

The funding organizations had no role in the design or conduct of the study; in the collection, analysis, and interpretation of the data; nor in preparation, review, or approval of the article.

Human Participant Protection: The study was approved by the IRB of Harvard Pilgrim Health Care Institute.

No financial disclosures were reported by the authors of this paper.

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