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ORIGINAL ARTICLE

The Impact of Electronic Medical Records on Timeliness of Diagnosis of Asthma

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We assessed timeliness of diagnosis of asthma before and after the inception of electronic medical record (EMR). The proportions of children with a delay in diagnosis of asthma before and after the inception of EMR were 67.8% and 56.8%, respectively ($p = 0.088$). A significant proportion of children have delayed diagnosis of asthma, and availability of EMR plays a minimal role in reducing delays in diagnosis of asthma. However, considering the limited statistical power and a potential trend of EMR toward the positive impact on timely diagnosis of asthma, the study results need to be revisited in a larger study.

Keywords asthma, time factor, medical records, computerized, electronic

INTRODUCTION

Electronic medical records (EMR)s are being used increasingly for either administrative or patient care purposes due to their potential advantages such as durability, confidentiality, easy accessibility, efficiency, and integrity. Thus, previous studies reported many benefits, for example, improving vaccination rate (1), optimizing treatment of asthma based on World Health Organization (WHO) guidelines (2), and predicting mortality risk for inner-city patients with reactive airways disease (3). Along these lines, EMRs have been reported to address some limitations of paper records, to facilitate workflow, to improve the quality of patient care and patient safety, to decrease medical errors, and more importantly access to one's medical records by multiple providers at the same time and at anywhere and anytime within a network (4–8). At a federal level, in 2005 the House of Representatives Ways and Means Committee emphasized the potential of information technology to dramatically improve the safety and quality of health care for Americans, while at the same time lowering costs through reductions in clinical errors and elimination of redundant procedures (9). The Department of Health and Human Services implemented an electronic billing process for Medicare and Medicaid in 2005 (10), and in 2003, the Institute of Medicine issued a report recommending adoption of EMR to improve patient-oriented outcomes, especially safety, quality, and care efficiency (11). Likewise, state governments are making similar efforts to implement health information technology at the state level and to form regional health information networks such as an immunization registry (12). Therefore, the implementation of EMRs

by health care providers for either administrative or patient care purposes will continue to increase in the future.

At present, the literature on the utility of EMRs in health care has focused on health care service outcomes such as medical errors or patient safety. However, there is paucity of literature that assesses the role of EMRs in specific disease-related outcomes, such as timeliness of diagnosis of asthma as examined in this study. A number of studies reported that asthma is frequently under-diagnosed, especially in children (13–17). Also, it is evident that delays in asthma diagnosis lead to a delay in accessing therapeutic and preventive health services, which may affect patients' asthma outcomes (13, 17, 18). Thus, timely diagnosis and treatment of asthma is crucially important for management of asthma. A system for health care providers such as an EMR system may help them make a timely diagnosis of asthma because it can potentially allow health care providers to access one's medical record anywhere and anytime within a network, whereas paper records often are difficult to be accessed at a setting where the patient's turn-around time is relatively quick such as urgent care or the emergency department (19). This study explored whether the introduction of the EMR system influences timeliness of diagnosis of asthma by conducting a retrospective cohort study that compared timeliness of diagnosis of asthma between the periods before and after the inception of EMRs in our study setting.

PATIENTS AND METHODS

Study Design and Setting

The study was a retrospective cohort study. Rochester, Minnesota, is centrally located in Olmsted County. The population in Olmsted County was 90.3% white compared with 89.4% white in Minnesota and 75.1% in the United States according to the 2000 census. Characteristics of the City of Rochester and Olmsted County populations were similar to those of the U.S. white population, with the exception of

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a higher proportion of the working population employed in the health care industry (20–22). Rochester, Minnesota, is an excellent setting to conduct a retrospective cohort study because medical care is virtually self-contained within the community with a unified medical record system among two medical centers for the past 90 years. This dossier-type medical record contains all inpatient and outpatient data that have been indexed in an automated form since 1935 (23). The recent study on the prevalence of asthma among children and adolescents in kindergarten through 12th grade in Olmsted County, Minnesota, showed that 17.9% of children and adolescents in kindergarten through 12th grade had ever had an asthma diagnosis (24).

The EMR system was introduced in a phase-wise manner at Mayo Clinic Rochester. The electronic clinical notes were introduced to Family Medicine on May 13, 1995, Community Pediatric and Adolescent Medicine (i.e., general pediatric practice) on June 29, 1995, Department of Pediatrics on September 11, 1996, Emergency Medicine on January 14, 1997, and Urgent Care Center (i.e., acute medical care service) on June 16, 1998.

Study Subjects

The study protocol was approved by the Institutional Review Boards at both the Mayo Clinic and at the Olmsted Medical Center. Study subjects were obtained from a convenience sample of 876 children who participated in a previous study, the Rochester Family Measles Project. Overall, the gender and ethnic distribution of the original study cohort are very similar to the demographic characteristics of the 1990 Olmsted County population, where 51% of the residents were female, and 96% were white (25). Study subjects were followed from their asthma index date to the date of their asthma diagnosis or last follow-up before 18 years of age.

Ascertainment of Asthma Cases

We conducted comprehensive medical record reviews for these children to determine their asthma status by applying

predetermined criteria for asthma. The criteria were developed during a previous study, and previous literatures on asthma epidemiology research have used these criteria to define asthma (26–28). These criteria are detailed in Table 1. We classified asthma status at index date into definite or probable asthma. In analysis, we combined these two categories because most probable asthma becomes definite asthma over time (21).

Timeliness of Asthma Diagnosis, Duration from Index Date to Asthma Diagnosis (Dependent Variable)

There were two dependent variables in this study: (1) the proportion of the subjects who had delayed diagnosis of asthma (i.e., discrepancy between index date and diagnosis date of asthma) and (2) the duration between index date and diagnosis date of asthma. Asthma status, as defined above, was determined first. Subsequently, asthma index date and asthma diagnosis date were determined. Asthma index date was defined as the earliest constellation of symptoms, including cough, dyspnea, and/or wheezing, found in the medical record that met the predetermined criteria for asthma in Table 1. Take, for example, a patient with a history of infantile eczema who was seen by a physician for a first episode of upper respiratory infection (URI)-associated wheezing, who at that visit was diagnosed with “bronchospasm” (symptom date). The patient did well for several months until the next URI, when he again developed wheezing. He was seen by a physician, responded well to an inhaled bronchodilator, and was diagnosed with URI-associated wheezing. For this particular patient, the time of that 2nd physician visit would be the asthma index date because he met the following criteria for asthma listed in Table 1: history of wheezing, periods of weeks or more when symptoms were absent, a history of infantile eczema, and a favorable clinical response to bronchodilators. Therefore, the index or incidence date of asthma reflects asthma status based on *our predetermined criteria for asthma* and a *longitudinal follow up, not onset of symptoms at a point in time*. Also, we developed specific

TABLE 1.—Asthma criteria.

Patients were considered to have *definite* asthma if a physician had made a diagnosis of asthma and/or if each of the following three conditions were present. They were considered to have *probable* asthma if only the first two conditions were present:

1. History of cough, dyspnea, and/or wheezing, OR history of cough and/or dyspnea plus wheezing on examination
And
2. Substantial variability in symptoms from time to time, or periods of weeks or more when symptoms were absent
And
3. Two or more of the following:
 - Sleep disturbance by nocturnal cough and wheeze
 - Nonsmoker (14 years of age or older)
 - Nasal polyps
 - Blood eosinophilia >300/uL
 - Positive wheal and flare skin tests or elevated serum IgE
 - History of hay fever or infantile eczema or cough, dyspnea, and wheezing regularly on exposure to an antigen
 - Pulmonary function tests showing one FEV₁ or FVC <70% predicted and another with at least 12% AND 200 mL improvement to an FEV₁, of >70% predicted Or a methacholine challenge test showing 20% or greater fall in FEV₁
 - Favorable clinical response to bronchodilator

Patients were excluded from the study if any of these conditions were present:

Pulmonary function tests that showed FEV₁ to be consistently below 50% predicted or diminished DLCO (diffusion capacity)

- Tracheobronchial foreign body at or about the incidence date
- Hypogammaglobulinemia (IgG <2.0 mg/mL) or other immunodeficiency disorder
- Wheezing occurring only in response to anesthesia or medications

The following diseases excluded the patient from study if they occurred before the incidence date:

- Bullous emphysema or pulmonary fibrosis on chest radiograph
- PiZZ alpha₁-antitrypsin
- Cystic fibrosis
- Other major chest disease such as juvenile kyphoscoliosis, or bronchiectasis

criteria regarding the time of asthma index date, and these criteria were used to estimate an approximate index date in cases where the onset of asthma was described in general terms. One example could be a patient who was described as having asthma for a few years. In this study, we consistently considered "a few years" to indicate 3 years before the date of the current physician encounter.

Date of asthma diagnosis was defined as the date of the earliest medical record diagnosis of asthma by physician. We considered asthma diagnosis to be a physician diagnosis of asthma, bronchial asthma, asthmatic bronchitis, allergic or exogenous or extrinsic asthma, intrinsic or endogenous or nonallergic asthma, infectious asthma, and reactive airway disease. On reviewing medical records, delay in diagnosis of asthma was defined as discrepancy between index date, when a patient met the criteria for asthma, and date of asthma diagnosis, when diagnosis of asthma was documented by physicians.

Independent Variables

The independent variables in this study were availability of EMR system. The first introduction of electronic clinical notes took place in pediatric practice on May 13, 1995. The subjects were divided into two groups according to index date of asthma in relation to the introduction of EMR system on May 13, 1995, i.e., the subjects with the index date of asthma before versus after May 13, 1995.

Statistical Analysis

To characterize the study subjects, descriptive statistics for sociodemographic factors were summarized. The delay in diagnosis of asthma was assessed by the duration between index date and the date of diagnosis of asthma. The proportion of subjects with a delay was determined and compared between the subjects whose index date of asthma was before May 13, 1995 (inception of electronic medical records) versus after May 13, 1995 using the chi-square test. Age and duration of follow-up were each compared between subgroups using the Wilcoxon rank sum test. The Kaplan-Meier method was used to estimate the cumulative probability of receiving an asthma diagnosis, following the index date. Subjects who had not yet received an asthma diagnosis before 18 years of age were censored at their date of last follow-up before 18 years of age. A Cox proportional hazards model was fit to evaluate the relationship between availability of EMRs and the time to asthma diagnosis after the index date. This statistical model takes into account for overall follow-up duration of the subjects in comparing timeliness of diagnosis of asthma between before and after the introduction of EMRs. The association was summarized by calculating the hazard ratios (HR) and corresponding 95% confidence intervals (95% CI). All calculated *p* values were two-sided, and *p* values less than 0.05 were considered statistically significant. Statistical analyses were performed using the SAS software package (SAS version 8.2; SAS Institute Inc, Cary, North Carolina, U.S.A.).

RESULTS

Study Cohort

Of the 876 children enrolled in the Rochester Family Measles Project, 839 had research authorization and com-

plete information for this study. At the time of the original study enrollment of the Rochester Family Measles Project, the prevalence of asthma was 18.5% (156 of 839), and 120 additional subjects developed asthma afterward. Thus, of the 839 children, a total of 276 met the criteria for asthma before 18 years of age (median age, 7.9 years; range 0.2-17.7 years), including 150 (54.4%) males and 259 (93.8%) Caucasians.

Among the 276 children, 202 had an index date before the inception of EMR (73.2%). The median age at index date of asthma was 5.7 (interquartile range [IQR] = 2.2-9.0) and 13.8 (IQR = 11.6-15.0) years, respectively, for subjects whose index date was before versus after the inception of EMRs (*p* < 0.001). The median duration of follow-up was 10.9 and 3.4 years, respectively, for subjects whose index date was before versus after the inception of EMRs (*p* < 0.001).

Overall, 97 (35.1%) of the 276 children had no delay in asthma diagnosis, whereas 179 had a delay. The median age at index date of asthma was 8.0 (IQR = 4.0-11.2) and 7.7 (IQR = 3.5-12.8) years, respectively, for the subjects with versus without delays in diagnosis of asthma (*p* = 0.44). The median duration of follow-up was 9.3 and 7.9 years, respectively, for the subjects with versus without delays in diagnosis of asthma (*p* = 0.13).

Among the 202 children who had an index date before the inception of EMR, 65 (32.2%) were diagnosed with asthma at the time of index date and 94 (46.6%) had a delay with a median of 569 days (IQR, 83 days-4.0 years), and 43 (21.3%) had a delay and still had not received an asthma diagnosis by the time of their last follow-up before 18 years of age. Among the 74 children who had an index date after the inception of EMRs, 32 (43%) were diagnosed with asthma at the time of index date, 28 (38%) had a delay with a median of 391 days (IQR, 67 days-2.1 years), and 14 (19%) had a delay and still had not received an asthma diagnosis. Thus, the overall proportions of the subjects with delays in diagnosis of asthma before and after the inception of EMRs were 67.8% and 56.8%, respectively (*p* = 0.088) (Table 2).

Based on a univariate Cox regression model, availability of an EMRs system minimally improved (14%) timeliness of diagnosis of asthma but did not reach statistical significance (HR = 1.14, 95% CI = 0.84-1.55, *p* = 0.40). Similar results were obtained after adjusting for both age at index date and duration of follow-up as defined by index date to last follow-up before age 18 (HR = 1.20, 95% CI = 0.79-1.82, *p* =

TABLE 2.—Comparison of subjects with an asthma index date, before and after EMR interception.

	Before EMR inception (%)	After EMR inception (%)	
<i>n</i>	202 (73.2)	74 (26.8)	
Subjects with no delays in diagnosis of asthma	65 (32.2)	32 (43.2)	
Subjects with delays in diagnosis of asthma (a)	94 (46.5)	28 (37.8)	
Subjects who have not been diagnosed with asthma (b)*	43 (21.3)	14 (18.9)	
Total number of subjects with delays in diagnosis of asthma (a+b)	137 (67.8)	42 (56.8)	<i>p</i> = 0.088
Median delay(days)	569 (IQR, 83 days– 4.0 years)	391 (IQR, 67 days– 2.1 years)	

IQR = Interquartile range.

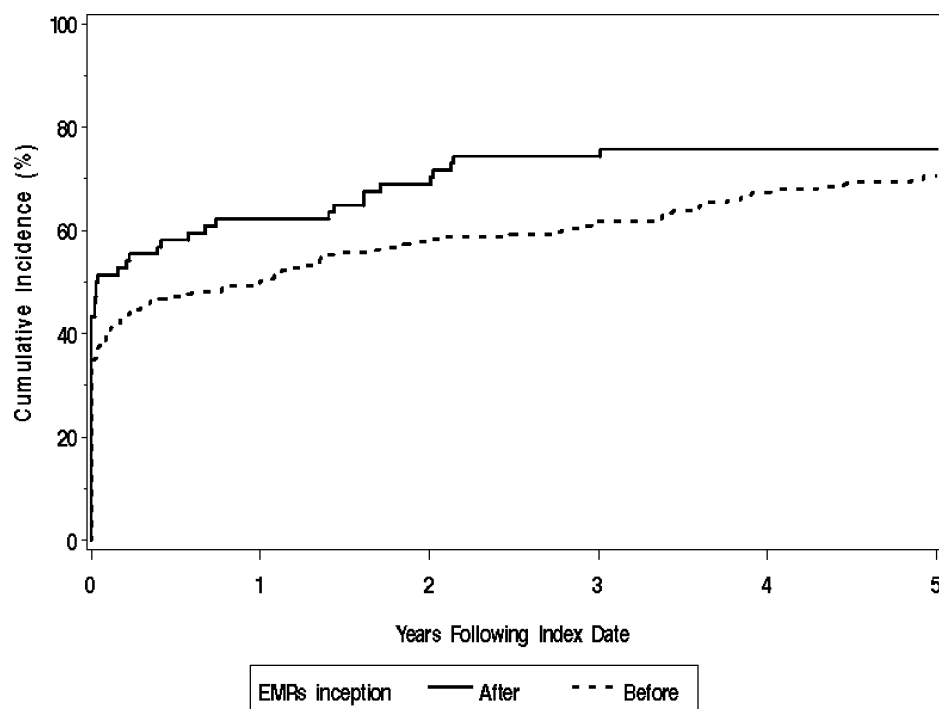


FIGURE 1.—Kaplan-Meier curve for cumulative probability of receiving an asthma diagnosis before age 18 years of age, following the asthma index date. Curves are depicted separately for subjects with an asthma index date before (---) versus after (—) EMR inception. The after-inception group showed consistent shortening of delay of asthma diagnosis compared with the before group, but there was no statistical significance. 0 month = index date.

0.39). This trend toward a consistent positive influence of the availability of EMRs on timeliness of diagnosis of asthma is further illustrated in the Kaplan-Meier curve (Figure 1).

DISCUSSION

Our study results suggest a significant proportion of children with asthma have a delay in diagnosis of asthma. Availability of EMR might not mitigate the concerns about delayed asthma diagnosis despite the tendency and trend of its positive influence. However, considering the sample size and a phase-wise implementation of EMR in our study setting, the potential positive impact of availability of EMR on timeliness of diagnosis of asthma or other asthma outcomes needs to be revisited. Based on our study results, we make a few recommendations for effective design and implementation of EMR to improve ability of health care providers to make a timely diagnosis of asthma in a patient care setting.

To our knowledge, this is the first report that assessed the influence of EMR on specific disease-related outcomes, particularly in asthma. Although availability of EMR in our study setting tends to reduce delays in diagnosis of asthma (67.8 to 56.8%) and shorten the duration for delays in diagnosis of asthma (569 to 391 days), these positive impacts may be clinically minimal or insignificant by considering that the significant proportion of the subjects after the inception of EMR still had delays in diagnosis of asthma. The duration of follow-up and ages at index date might be important confounding factors that, however, were not associated with delays in diagnosis of asthma and, thus, were unlikely to confound the results. However, our study results should not be a reason to dismiss prematurely the values of EMR in patient

care or administrative support and need to be interpreted cautiously. Given the absence of any intervention in our study to promote use of EMR, our study results might not surprise but rather encourage us to consider its positive trends toward improvement in timely disease diagnosis. In addition, the implementation of EMR in our study setting was stepwise, so the impact of EMR on asthma diagnosis might not have been fully captured because of incomplete implementation among departments within the institution and among institutions in our community. Furthermore, our small sample size clearly limits our ability to fully assess our study hypothesis. Based on a two-sided chi-square test with a type I error of 5% the power to detect a difference in the proportions of the subjects with delay in diagnosis of asthma between before (67.8% and $n = 202$) and after (56.8% and $n = 74$) the inception of EMR was 39%. Thus, our study results are subject to a type II error (i.e., fail to reject null hypothesis despite that the null hypothesis is not true). Therefore, our study results need to be interpreted in a lieu of the existing literature supporting the positive impact of EMR on various health service outcomes.

Indeed, EMRs are being used increasingly as tools for patient management and may offer substantial advantages over paper records (29, 30). EMR may address many limitations of paper records (4–6, 8) and most importantly, it allows health care providers access to one's medical records at anywhere anytime within a network, which was highlighted by a recent article (8). This notion mitigates a common misconception that the difference between paper records and EMRs is a physical location of storage of information. At present, in the U.S., EMR systems were adopted only in 5% to 10% of practices in 2003 (31). However, the paperless trends at federal

and state levels are likely to drive future trends toward EMR not because of administrative reasons but because of intrinsic benefits of EMR, e.g., accuracy of information documented in EMR or effective health care utilizations (7, 12, 31). Therefore, EMR has clearly built-in advantages over paper records if designed and implemented properly.

A number of studies reported that asthma is frequently under-diagnosed, especially in children (13–17). Also, previous studies suggest that delay in asthma diagnosis may lead to a delay in accessing therapeutic and preventive health services and, thus, delay in diagnosis of asthma can result in a delay in treatment of asthma that affects patients' asthma outcomes (13, 17, 18). Early diagnosis and treatment of asthma is crucially important to management of asthma (19). We believe that EMR can be a useful tool to help health care providers make a timely diagnosis of asthma. To meet the goal, we recommend the following features of EMR to be incorporated. First, EMR needs to be equipped with a user-friendly query function by health care providers. This function will help health care providers identify any history of asthma-related symptoms, medications, visits, hospitalizations, and tests in relation to specific timeframes and is likely to help health care providers make a timely diagnosis of asthma. Second, EMR needs to incorporate existing guidelines or pertinent information for asthma management in a way to support health care providers' decision. Benin et al. reported a useful role for the EMR that improved adherence to the guidelines for the test of pharyngitis and provided more proper medication to patients (32). Finally, after electronic clinical notes are effectively integrated with databases for laboratory and imaging test results, pharmacy databases, and administrative databases, a function displaying multiple EMR programs on a single screen would be helpful for health care providers to incorporate the advantage of paper records into EMR.

Strengths of our study include ascertainment of asthma status by predetermined, established criteria. We also had the advantage of access to comprehensive medical records, which include all of subjects' outpatient and inpatient records, emergency department records, pulmonary function testing, laboratory testing, and imaging studies. Another strength of our study is a self-contained health care environment with unified medical records systems among health care providers in our community.

However, there are also limitations in our study. Some limitations are inherent to its retrospective design. For example, the study subjects are a sample or product of population who moved in and out of the community. However, sociodemographic characteristics between migrants and nonimmigrants of the birth cohort born in Olmsted County between 1976 and 1982 ($N = 8,548$) were assessed by a previous study, and they found that migrants and non-migrants were epidemiologically quite similar (22). Thus, migration is unlikely to affect the study results.

We have discussed other limitations above that include lack of intervention, a small sample size, incomplete implementation of EMR in our study setting, and limited follow-up of the subjects only during the first 18 years of life. In addition, our study had a high cumulative incidence of asthma in the study cohort (32.9% during the first 18 years of life). However, at the time of the original study enrollment of the Rochester

Family Measles Project, the prevalence of asthma was 18.5% (156 of 839), which is close to the prevalence of asthma (17.9%) among K through 12 children and adolescents in our community (24). Although the reason for the increased identification of asthma status after the study enrollment is not entirely clear, our study cohort appears to over-represent families with a higher risk of asthma because our study was based on the original Rochester Family Measles Project cohort, a convenience sample 5 to 12 years of age who were recruited from the public school system in Rochester, Minnesota. However, this should not influence the study results.

In conclusion, a significant proportion of children have delayed diagnosis of asthma. Availability of EMR plays a minimal role in reducing delays in diagnosis of asthma in our study setting. However, considering the limitations of our study and a potential trend of EMR toward the positive impact in timely diagnosis of asthma, assessment of the impact of EMR on timely diagnosis of asthma, or other outcomes needs to be revisited in future studies. The features of EMR for the effective design and implementation need to be considered.

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