Ten year trends in hospital encounters for pediatric asthma: an Indiana experience

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Introduction: Pediatric asthma is a common cause of emergency department visits, hospital admissions, and mortality. Population incidence studies have historically used large-scale survey data. We measured these epidemiologic trends using a health information exchange.

Methods: In this retrospective cohort study, we used electronic health record data from a regional health information exchange to study clinical trends in pediatric patients presenting to the hospital for asthma in the State of Indiana. Data was obtained from 2010 – 2019 and included all patients ages 2-18 years. Study participants were identified using international classification of disease codes. The measured outcomes were number of hospital encounters per year, percentage of admissions per year, and mortality rates.

Results: Data included 50 393 unique patients and 88 772 unique encounters, with 57% male patients. Over the ten-year period, hospital encounters ranged from 5000 to 8000 per year with no change in trajectory. Between 2010 and 2012, the percent of encounters admitted to the hospital was ~30%. This decreased to ~20-25% for 2015-2019. Patient mortality rates increased from 1 to 3 per 1000 patient encounters in 2010-2014 to between 5 and 7 per 1000 patient encounters from 2016-2019. White patients had a significantly higher admission percentage compared to other racial groups, but no difference in mortality rate.

Conclusions: Asthma continues to be a common condition requiring hospital care for pediatric patients. Regional health information exchanges can enable public health researchers to follow asthma trends in near real time, and have potential for informing patient-level public health interventions.

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Introduction:

Asthma is the most common chronic illness of childhood.[1, 2] Children of all ages present to the hospital for diagnosis and treatment of this disease, and recent studies show the prevalence of asthma may be increasing worldwide.[3-5] Not only does this present a challenge for outpatient and emergency department providers, but many patients die from complications of severe asthma each year.[6, 7] A unique feature of asthma is that it appears to affect children differently depending on their racial and ethnic background, environmental exposures, and their family's socioeconomic status.[8-17] An understanding of the epidemiology of pediatric asthma is key to diminishing the negative impact it has on affected children and their families.

Historically, the primary source of data to investigate the incidence and prevalence of pediatric asthma in the United States has been national census surveys.[18] While informative, this data has two primary drawbacks. First, it is not current, with a typical 2-year delay from collection to widespread dissemination. Second, it is survey data and is thus prone to recollection and response bias, among others.[19-21] These limitations can delay needed epidemiologic information, and potentially lead to missing or biased data.

With the surge in the use of electronic health record (EHR) systems, massive amounts of patient-level healthcare data are being produced on a daily and even hourly basis. These data are becoming more accessible with improved interoperability through large-scale health information exchanges. It is already being used to inform practitioners as they study and treat childhood asthma.[22-24] The nature of these types of data are useful because it does not have the delay or biases that national census surveys have. The goal of this study was to use the patient-level EHR data from an extensive regional health information exchange to characterize the incidence and demographic factors of pediatric patients presenting to the hospital for asthma, as well as their clinical outcomes.

Methods:

This retrospective cohort study sought to analyze recent trends in the incidence, demographics, and clinical outcomes of pediatric patients presenting to the hospital for asthma. The study population included all patients ages 2 to 18 years who presented to the hospital for asthma symptoms from January 2010 to December 2019. Asthma symptoms were identified using the International Classification of Diseases (ICD) 9 or 10 codes depending on the year of the encounter. Age was determined at the time of the patient's initial presentation to the hospital, either in the emergency department or inpatient setting. If a patient was admitted to the hospital from the emergency department, the encounter was included as an inpatient encounter and not an emergency department encounter. The inpatient setting includes both hospital floor or ward and intensive care unit. No outpatient encounters were captured. Predictor variables used for statistical analysis include gender, race, ethnicity, insurance status, and RUCA coding label. Outcomes evaluated included annual hospital encounter rates, annual hospital admission rates both total and by patient age, and patient mortality rates. Hospital admission rates were

calculated by dividing the number of inpatient encounters for each year divided by the number of total hospital encounters (emergency department plus inpatient) each year. Mortality rates were calculated by dividing the number of mortalities per year by the total number of unique patients seen each year. The study hypothesis is that the use of the data obtained from a regional health information exchange will allow for the assessment of annual hospital encounter rates, hospital admission rates, and mortality rate trends for pediatric asthma.

Data for this study were obtained from the Indiana Network for Patient Care (INPC). The INPC is a large, comprehensive regional health information exchange that includes data from more than 90% of the hospitals in Indiana and over 17 million unique patients. The data includes hospitals from all five of Indiana's major hospital systems, and includes both large, academic medical centers as well as smaller, community-based hospitals.[25] Data from the INPC has been used in several previously published studies in various clinical areas, including disease surveillance, hospital follow-up, cancer registries, and more.[26-35] A recent article demonstrated the INPCs efficacy in tracking the COVID-19 pandemic.[36]

Data obtained included unique study IDs for each patient, encounter IDs, patient demographics including age, gender, race, and ethnicity, diagnoses (ICD codes), admission/discharge dates, insurance provider, setting of encounter (whether in the emergency department or as an inpatient), mortality, and hospital length of stay. Urban or Rural classification was made based on patient zip codes using the Rural-Urban Classification (RUCA) Coding version 1.11. Calculations involving race, ethnicity, RUCA coding, and mortality were done using unique study IDs. Calculations involving age and hospital admissions were done using unique encounter IDs. Data was stored in a secure data server housed in the Regenstrief Institute. All protected health information was removed during the data extraction except for admission dates, discharge dates, and birth dates. This study was reviewed by the Indiana University Institutional Review Board and was granted exempt status.

An additive negative binomial regression model was applied to describe the predicted annual incidence of hospital encounters for asthma in Indiana by age in years. This model belongs to the family of generalized additive models (GAM).[37] GAM models accommodate for non-linear variable effects in an additive fashion by calculating a specific function parameter for each individual variable included in the model. The formula for this type of model is shown here:

$$y_i = B_0 + \sum_{j=1}^{p} f_j(x_{ij}) + \in_i$$

The annual incidence rate of hospital encounters for asthma in Indiana was modeled as a smooth function of age and estimated by the observed data. A 5% significant level was applied to the model and the interval bands can be seen as the grey ribbon surrounding the curve. This model, relative to the base overall data obtained from the INPC, allows the yearly age incidence prediction with decreased variability. Categorical comparisons for proportions of hospital admissions, insurance type, and mortality rates by race were conducted using chi-square tests with an alpha level of 0.05. All figures, data manipulation, regression models, and statistical tests were completed using RStudio v. 1.3.1093,[38] and extension packages mgcv, dplyr, and tidyverse were used.

Results:

Initial results from our data extraction for the specified diagnostic population during the study period identified 50 393 unique patients and 88 772 unique patient encounters. A summary of the patient data is provided in table 1. Ethnicity data were also collected but had a large missing rate of nearly 43%, and thus will not be further discussed.

Figure 1 illustrates the distribution of hospital encounters in our population by county. Most encounters were from the center of the State, with another large group at the most Northwestern portion of the State. Based on the RUCA coding, the yearly average percentage of hospital encounters for patients from urban areas was 88.7%, with the remaining 11.3% coming from rural areas. The age of each patient at the time of their encounter, as well as patients' gender distribution are illustrated in Figure 2. Our data demonstrate a transition from predominantly males to predominantly females at age 13.

Figure 3 demonstrates the additive negative binomial regression model. This model predicts the incidence of hospital encounters for asthma based on patient age in years. The model predicts the highest amount of annual patient encounters at age 2, with a predicted annual incidence of 824 hospital encounters for asthma. The 5% confidence bands in this age group are large and stretch from 480 annual encounters to 1415 annual encounters, with a range of 935. As the patient age increases, the model's center line has a slow, steady downtrend that is near linear. The slope indicates that the predicted annual hospital encounters for asthma decreases between 30 and 40 encounters per year for each one year increase in age. The minimum is 280 encounters per year at age 18. Of note, the model's confidence bands are the tightest in the middle age groups, between ages 10 to 14, with a minimum range of 250 at age 12. After age 14, the confidence bands widen slightly, and at age 18 have a range of 288.

The yearly number of encounters was recorded for both the emergency department setting as well as inpatient encounters. The results are illustrated in figure 4. The emergency department trend shows a steady encounter rate between 6000 and 8000 encounters per year, with a minimum of 5163 ED encounters in 2018. The number of inpatient encounters demonstrates a steady decline from 2010 to 2015 followed by a plateau at around 1000 patient encounters per year from 2016 to 2019. Data from the U.S. Census for Indiana in 2019 reports a total population of 6 732 219, with 1 568 607 persons under age 18.[39] Our data indicates a total of 7743 hospital encounters for asthma in 2019, showing that 0.49% of the pediatric population of Indiana presented to the hospital for asthma in 2019. This provides an approximation of the prevalence of asthma that required presentation to the hospital in the pediatric population of Indiana.

Comparing the number of inpatient encounters to emergency department encounters, we were also able to assess the admission rates or percentages per year. These results are illustrated in figure 5. The graph depicts a nearly 10 percent reduction in the percentage of patients admitted to the hospital for asthma during the study period, from 30 percent in 2010 to 20 percent in 2019. Most of the reduction was seen from 2010 to 2015. From 2015 to 2019 there appears to be a slight uptrend in the admission percentage per year. The past five years

have seen admission percentages close to 20 percent with a peak of 25 percent in 2018. This means that for every ten pediatric patients who present to the emergency department for asthma, two of them on average are being admitted for the past five years.

Using the mortality data for each patient, we analyzed the mortality trend in our population. The results are shown in figure 6. This figure illustrates an increasing mortality rate in the study population. Initial mortality rates were between one and two patients per thousand hospital encounters for asthma in 2010 and 2011. This rate has grown since 2014, and now ranges between 5 and 7 mortalities per thousand hospital encounters for 2016 to 2019. The year 2014 had the lowest recorded mortality rate at 0.57 mortalities per 1000 patient encounters, and the year 2018 had the highest recorded mortality rate at 6.2 mortalities per 1000 patient encounters.

Stratifying our population by race, we compared the insurance status (Medicaid vs. non-Medicaid), admission percentage, and the mortality rates for the three most prevalent racial groups. These results are displayed in table 2.

Based on the December 2019 Indiana Medicaid Enrollment Report, the percentage of children in Indiana covered by State Medicaid Insurance was 39.62%.[40] The study population had higher Medicaid enrollment percentages in all racial groups, indicating that pediatric patients who present to the hospital for asthma are more likely to be covered by Medicaid than the general population. The percentage of patients with Medicaid insurance was significantly different between the racial groups, with the White population having a significantly lower percentage than both the Black and Asian groups. Admission percentage was significantly higher in the white racial group and significantly lower in the Black and Asian racial groups. This was not seen in the mortality rate for each group, however, with the Asian group having the lowest mortality rate, but this was not found to be significantly different on formal comparison testing. Thus, it appears that while the white population has a higher likelihood of being admitted to the hospital for asthma, this does not translate into a lower mortality rate for this population.

Discussion:

In this retrospective cohort study, a state-wide health information exchange was utilized to assess the patient-level characteristics of pediatric patients presenting to the hospital for asthma, and to evaluate the clinical outcomes for this population. It was demonstrated that hospital encounters for pediatric patients with asthma are affected by a patient's age and gender. Emergency department encounters for this population have remained consistent in the past decade, but hospitalizations have not, leading to a decrease in the overall percentage of patients admitted. Although the admission percentage is decreasing, there is evidence of an increase in mortality rate. While there are racial differences in insurance status and hospital admission percentage, there is no significant differences in mortality. Having current and accurate data regarding the epidemiologic trends of pediatric asthma is crucial to improving patient outcomes. As asthma is an illness with unique risk factors based not only on a patient's genetics but also on environmental exposures, this provides more of an incentive to understand the population-level trends of this disease.[41, 42] The EHR data obtained in this study from more than 90% of the patients in Indiana provides a unique view of the disease trends in pediatric asthma.

In the past 10 years we can notice patterns in the patient factors of children presenting to the hospital for asthma. This age distribution is consistent with the clinical characteristics of asthma, in that many patients who have asthma symptoms at younger ages will often “outgrow” their illness and experience symptom resolution as they grow older. The additive negative binomial regression model demonstrated clear age incidence trends with younger children having a higher incidence of hospital encounters for asthma that declines steadily to a minimum in the late teenage years. Another unique feature of pediatric asthma is that at younger ages, the population affected is primarily males. However, in the adult population, there are more females with asthma than males. This transition has been described in previous studies that reported the transition around adolescence and hypothesized that the sex hormones produced during puberty were responsible for the observed change.[43] This is consistent with both the data and hypothesis of previous studies.

Despite the data illustrating a consistent number of hospital encounters for pediatric asthma patients, the total number of inpatient encounters appears to decrease. This widening gap leads to the trend seen in figure 5 of the decreasing hospital admissions rate over the 10 years study period. There are several possible explanations for this trend. One is the improvement of pediatric asthma care by emergency medicine physicians. With ongoing community outreach educational programs, the pediatric education of adult emergency medicine physicians in Indiana has led to the improvement in overall pediatric readiness.[44] Another is a possible improvement in outpatient provider access, which would lead emergency medicine providers to feel more comfortable discharging patients in the midst of an asthma exacerbation rather than admitting them to the hospital overnight. Lastly, a promising area of research to improve outcomes in this study population focuses on improving patient and family education.[45, 46] It is possible that overall patient education has improved in the past decade, leading patient families to feel more comfortable managing their child’s asthma at home with appropriate prescription medications rather than staying overnight in the hospital.

In contrast to the decreasing trend of pediatric hospital admission rates for asthma, the mortality trend appears to be increasing. Although decreasing hospital admission rates are typically viewed positively, doing so at the expense of an increase in pediatric asthma mortality would be a problem. Worsening environmental conditions that may provoke severe asthma exacerbations may bear some responsibility for this observed trend. Vaping has become a popular teenage activity in the past decade, and a recent study showed that vaping use is more prominent among adolescents with asthma than their non-asthmatic peers.[47] While there are other possible explanations for this pattern, providers should be cautious that they are not trading a decrease in asthma hospital admissions for an increase in mortality rate. Investigations into those patients at highest risk for asthma related mortality are needed to mitigate this upward trend.

Previous studies have repeatedly shown a difference in the burden of pediatric asthma based on a patient’s race, ethnicity, and socioeconomic status.[10, 12, 14, 16] Our data were able to accurately capture the racial demographics for each patient and showed a significant difference in the admission percentage based on race. Both Black and Asian populations had a lower percent of hospital admissions for asthma compared to the White population. While this discrepancy is concerning, it would be more concerning if there was a difference in mortality rates. This was not seen in our data, with no significant difference between the groups and the Asian population having the lowest mortality rate. While it is difficult to draw absolute

conclusions based on this data, it does provide some reassurance that while it is possible that the care provided to each patient might be different based on a patient's race, this does not appear to translate into higher asthma mortality.

This study provides an example of the usefulness of large-scale regional health information exchanges. Adult studies have used similar methods and shown them as a plausible and effective way to describe asthma epidemiology.[48] As we move into a new decade, the benefits of big data arising from the continuous collection of granular healthcare information will continue to be more recognized. In this case, the availability of the statewide health information exchange data made it possible to analyze near-real-time trends of a specific disease. In the future, if more states had such regional health information exchanges, scientists could analyze differences in asthma incidence and prevalence between states in near-real-time and identify specific regions with higher disease burden. This could lead to specific environmental exposures being identified and then potentially removed to improve the health of the population in that area. For example, 2019 saw the development of a new respiratory illness, E-cigarette, or Vaping Product, Use Associated Lung Injury (EVALI).[49] This illness was found to contribute to increased frequency of acute asthma exacerbations in adolescents.[50] Using a regional health information exchange to monitor trends in asthma hospitalizations has the potential to identify new disease triggers, such as EVALI, earlier after emergence, and direct public health interventions to decrease the morbidity associated with the new disease. As data availability increases, future work will improve its dissemination and lead to patient-level interventions and effective public health interventions.

Research done using this type and scale of health data does have limitations. Changes to the health information exchange itself can cause changes to be seen in the patient data that are not reflective of a patient or disease trend. Also, missing data can provide an obstacle to analysis. The data on ethnicity showed a significantly decreased mortality in the Hispanic population, which is in stark contrast to many prior studies which show the opposite.[51-53] Upon further investigation, the ethnicity factor had nearly 43% of patients with missing data. As with all observational data, we are limited in the ability to make conclusions regarding the trends in our data and are prone to potential confounders. In this case, our study is limited by having no information on our patients' access to primary care, asthma controller medications, or asthma action plans. Also, as the INPC data does not cover 100% of hospitals in Indiana, the prevalence data will be unable to measure the true prevalence of hospital encounters for asthma across the entire State. Finally, the data is confined to the State of Indiana, and may not be generalizable to other States.

Conclusion:

Pediatric asthma is a common cause of hospital encounters. Trends over the last decade indicate a decrease in the admission rates for this population but a potential increase in mortality rates. Large regional health information exchanges offer a significant opportunity to increase the speed and availability of data access for public health research. This improvement has potential to both develop and coordinate meaningful patient-level public health interventions in response to changing epidemiologic trends.

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Table 1: Patient Demographics

Patient Characteristics	Counts
Unique Patients	50 393
Unique Patient Encounters	88 772
Gender	
Male	28 699 (57.0%)
Female	21 658 (43.0%)
Encounter Type	
Emergency department	68 154
Inpatient	20 618
Race	
White	30 473 (60.5%)
Black	12 695 (25.2%)
Asian or Pacific Islander	1556 (3.1%)
Other or Unknown	5526 (11.0%)

Demographic	Medicaid Percentage	Admission Percentage	Mortality Rate per 10,000 Patients
White	43.8*	25.6*	36.1
Black	72.0*	20.4*	34.7
Asian	71.0*	20.8*	25.7

Table 2: Admission, Insurance, and Mortality Data by Race

*: Race-specific proportions were compared using a chi-squared test and significantly different at an alpha level of 0.05.