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Developing a risk stratification model for predicting future health care use in asthmatic children

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ABSTRACT

Background: Previous studies have stratified pediatric asthma patients for risk of future exacerbation and/or health care use, but most incorporate multiple clinical parameters.

Objective: To determine whether historical acute care visits (ACVs) alone could predict risk of future health care use.

Methods: Children seen for asthma in an outpatient visit during a 3-year period were identified. The number of ACVs in the 12 months before and after the outpatient visit was determined. Logistic regression models were used to determine the odds of a future ACV. Models were adjusted for age, sex, race, and insurance status.

Results: Of 28,047 outpatient visits, 21,099 (75.2%) had no historical ACVs. The probability of a future ACV increased from 30% with one historical ACV to 87% with 5 or more historical ACVs. Outpatient visits with one historical ACV had significantly higher odds of a future ACV compared with those with no historical ACVs (adjusted odds ratio [OR], 3.60; 95% confidence interval [CI], 3.14–4.12; $P < .001$). The OR increased with each additional historical ACV to an adjusted OR of 58.71 (95% CI, 24.34–141.61; $P < .001$) with 5 or more historical ACVs. Outpatient visits with 5 or more historical ACVs represented only 1.1% of the study sample but accounted for a higher mean number of future ACVs.

Conclusion: The historical count of ACVs was predictive of future ACVs. A significant increase in the probability of future ACVs was observed with each additional historical visit, effectively stratifying risk by the historical visit count. Notably, a small group of patients accounted for a disproportionate number of future ACVs.

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Introduction

Asthma is one of the most common chronic pediatric diseases in the United States, with 10.5 million children reported to be affected. The burden of childhood asthma is significant, with asthmatic children more likely to have emergency department and urgent care visits than asthmatic adults and more likely to miss school due to asthma than adults are to miss work.¹

Several studies have stratified patients with pediatric asthmatic or risk of future asthma exacerbation and/or health care use, but most incorporate multiple clinical parameters.^{2–7} Unfortunately,

health care professionals and those who conduct disease management, community outreach, and environmental assessment efforts often do not have access to multiple clinical data parameters. Even with access to this information, existing models are often cumbersome and difficult to incorporate into busy clinical practice. For example, although the National Heart, Lung, and Blood Institute guidelines define *risk* as frequency of exacerbation that requires systemic corticosteroids, it is often difficult for health care professionals and families to quantify this frequency.⁸ Therefore, a simple and practical risk stratification model would be extremely useful in identifying those asthmatic patients at high risk of future health care use.

Our study examined the association between the frequency of historical asthma-related acute care visits (ACVs) and the likelihood of future health care use. We hypothesized that higher levels of past

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use would be associated with increased risk of future use and anticipated that a relatively small number of patients might account for a disproportionate amount of ACVs.

Methods

Study Sample

This study was conducted at Children's Mercy Hospital, a tertiary care, free-standing children's hospital in Kansas City, Missouri, that serves a large Midwestern metropolitan area and the surrounding region. We included children aged 3 to 17 years seen for an asthma diagnosis (*International Classification of Diseases, Ninth Revision* [ICD-9], codes 493.xx) in an outpatient primary care, allergy-asthma-immunology, or pulmonology clinic from January 1, 2010, through December 31, 2012, in our sample. Because the intent was to identify all active outpatients with asthma in our patient population, we did not exclude any outpatient visits with asthma as a secondary diagnosis. In addition, each outpatient visit was considered a unique entry, even if multiple outpatient visits were accounted for by the same patient. Demographic data collected for each outpatient visit included age, sex, race, and insurance type (public vs commercial). Age was divided into quartiles for analysis of the potential effect of age distribution on future ACVs, without using an arbitrary cutoff. Approval was obtained from the Children's Mercy Institutional Review Board, and informed consent was waived.

Asthma-Related ACVs

ACVs were defined as encounters in the emergency department (ED), urgent care center (UCC), or inpatient admission for a primary diagnosis of asthma (ICD-9 codes, 493.xx). At each identified outpatient visit, the number of ACVs for that particular patient in both the preceding 12 months (historical) and following 12 months (future) was determined (Fig 1). Instances of multiple encounter types on the same date of service were considered to be a single ACV (a patient with an encounter in the ED who was subsequently admitted for inpatient hospitalization).

Data Analysis

Historical ACVs were modeled as a categorical factor representing the total number of ACVs in the 12 months before each outpatient visit. Future ACVs were modeled as a binary outcome, which indicated whether an ACV occurred within the 12 months after the outpatient visit. We explored the bivariate association between historical ACVs and visit characteristics (age, sex, and race) with future ACVs using the Pearson χ^2 statistic. Multivariate logistic models were used to determine the odds of a future ACV. All logistic models accounted for the clustering effect of some patients having more than one outpatient visit during the 3-year period. Linear Wald tests were performed to compare the equality of regression coefficients, with the intent to determine whether the association between historical and future ACVs were differentially distributed

based on the type of ACV (UCC, ED, or inpatient admission). Statistical significance was assumed at $P < .05$ (2-tail). Analyses were completed using Stata statistical software, version 13 (StataCorp, College Station, Texas).

Model Validation

To evaluate the model performance, a 10-fold cross-validation was completed. The data were randomly partitioned into 10 subsamples of equal size, with a single subsample serving as the validation data and the remaining 9 subsamples used as the training data. Receiver operating characteristic curves were used to compare the area under the curve (AUC) from the cross-fold validation with the AUC from the original regression model. The AUC measures discrimination, specifically the ability of our model to correctly classify those with and without a future ACV. An AUC value of 0.50 indicates no discriminative value (50% sensitivity and specificity), whereas an AUC of 1.0 (100% sensitivity and specificity) indicates a perfect fit of the model.

Results

Study Sample

There were 28,047 outpatient visits identified, representing 10,785 individual patients. Visit characteristics are listed in Table 1. At most visits, patients were male (59%) and black (43%), and 65% had public insurance (Medicaid). Fifty-one percent of visits were at a primary care clinic, and 49% were at a subspecialty clinic. A primary diagnosis of asthma was documented in 16,610 (59.2%) of all outpatient visits. Visits in a primary care clinic were less likely to have a primary diagnosis of asthma compared with subspecialty clinics (42.2% vs 77.1%). The most common alternative primary diagnoses included routine child health examination (15.4%), rhinitis (9.8%), and acute upper respiratory tract infection (1%).

Asthma-Related ACVs

A total of 10,473 ACVs were identified from January 1, 2009, through December 31, 2013, with 55% of encounters occurring in the ED, 25% in the UCC, and 20% as inpatient admissions. Of 28,047 outpatient visits, 21,099 (75.2%) had no historical ACVs, whereas 4,349 (15.5%), 1,519 (5.4%), 544 (1.9%), 224 (0.8%), and 312 (1.1%) had 1, 2, 3, 4, and 5 or more historical ACVs, respectively.

Table 1
Outpatient visit characteristics

Characteristic	No. (%) of visits (n = 28,047)
Age quartile (age range, y)	
Quartile 1 (2.9–5.8)	7,012 (25.0)
Quartile 2 (5.8–8.9)	7,013 (25.0)
Quartile 3 (9.0–12.5)	7,011 (25.0)
Quartile 4 (12.5–18)	7,011 (25.0)
Sex	
Male	16,516 (58.9)
Female	11,531 (41.1)
Race	
Black	12,028 (42.9)
White	9,978 (35.6)
Hispanic	4,408 (15.7)
Other	1,633 (5.8)
Insurance	
Public	18,353 (65.4)
Commercial	8,331 (29.7)
Other	1,363 (4.9)
Visits to primary care clinic	14,366 (51.2)
Primary asthma diagnosis	6,064 (42.2)
Visits to specialty clinic	13,681 (48.8)
Primary asthma diagnosis	10,546 (77.1)

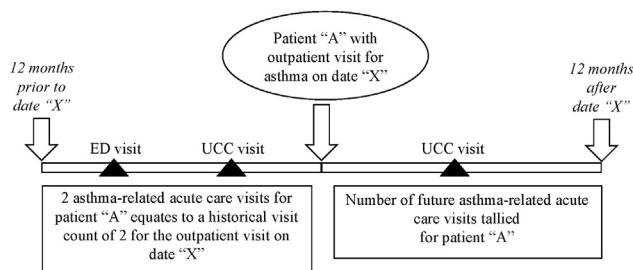


Figure 1. Determination of historical and future asthma-related acute care visits.

Type of Historical Asthma-Related ACV

To develop the model, it was necessary to determine how much weight to give each type of ACV. The equivalency of 1 ED visit vs 1 inpatient visit vs 1 UCC visit, 2 ED visits vs 2 UCC visits vs 2 inpatient visits, and so on were empirically tested. The results indicated that the type of ACV had no differential effect and did not necessitate either type-specific coefficients or adjustment (conditional weighting). For that reason, the final model gave each type of ACV equal weights.

Probability of Future Asthma-Related Acute Care Visits

Figure 2 shows the predicted probability of future ACVs based on the count of historical ACVs. The probability of a future ACV increased with each additional historical ACV, from approximately 30% with a single historical ACV to 87% with 5 or more historical ACVs. Outpatient visits with no historical ACVs still had a 10.2% probability of a future ACV.

Logistic Regression

Unadjusted and adjusted logistic regression models are given in Table 2. The odds of a future ACV increased with each additional historical ACV ($P < .001$, test for trend), even after adjusting for age, race, and insurance type. Outpatient visits with one historical ACV had significantly higher odds of a future ACV (adjusted odds ratio [OR], 3.60; 95% confidence interval [CI], 3.14–4.12; $P < .001$) compared with outpatient visits with no historical ACV. The OR doubled when comparing 2 historical ACVs against none (OR, 7.14; 95% CI, 5.81–8.77; $P < .001$) and continued to increase with each additional historical ACV up to an adjusted OR of 58.71 (95% CI, 24.34–141.61; $P < .001$) with 5 or more historical ACVs.

Demographics and Future Asthma-Related ACVs

When considering the influence of race, the odds of a future ACV increased for visits in which patients were black (unadjusted OR, 2.16; 95% CI, 1.71–2.72; $P < .001$) or Hispanic (unadjusted OR, 1.74; 95% CI, 1.33–2.27; $P < .001$) compared with white (Table 2). At outpatient visits with public insurance, the odds of a future ACV were increased (unadjusted OR, 1.71; 95% CI, 1.39–2.12; $P < .001$) compared with commercial insurance. Similar trends were observed in the adjusted model, with the exception of public insurance, which became insignificant (adjusted OR, 1.21; 95% CI, 0.99–1.47; $P = .06$).

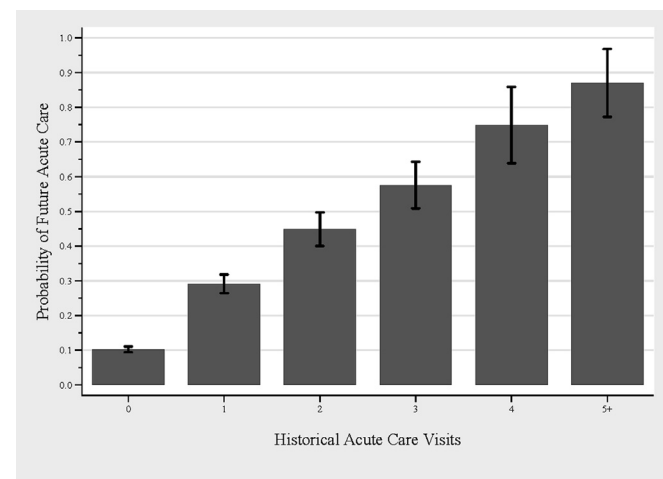


Figure 2. Predicted probability of future asthma-related acute care visits by historical acute care visit count.

Table 2

Adjusted and unadjusted logistic regression models (n = 28,047)

	Unadjusted model		Adjusted model	
	OR (95% CI) ^a	P value	OR (95% CI) ^b	P value
Historical ACVs				
0	1 [Reference]	...	1 [Reference]	...
1	3.98 (3.49–4.53)	<.001	3.60 (3.14–4.12)	<.001
2	7.99 (6.51–9.81)	<.001	7.14 (5.81–8.77)	<.001
3	13.19 (9.93–17.52)	<.001	11.89 (8.95–15.80)	<.001
4	29.45 (17.02–50.99)	<.001	26.12 (14.46–47.17)	<.001
≥5	60.78 (27.87–132.57)	<.001	58.71 (24.34–141.61)	<.001
Age				
Quartile 1	1.81 (1.36–2.40)	<.001	1.76 (1.40–2.21)	<.001
Quartile 2	1.33 (0.99–1.78)	.05	1.27 (1.01–1.61)	.04
Quartile 3	1.27 (0.92–1.74)	.14	1.28 (1.0–1.66)	.05
Quartile 4	1 [Reference]	...	1 [Reference]	...
Race				
Black	2.16 (1.71–2.72)	<.001	1.66 (1.34–2.06)	<.001
Hispanic	1.74 (1.33–2.27)	<.001	1.42 (1.13–1.79)	<.001
Other	1.78 (1.18–2.70)	.01	1.48 (1.08–2.04)	.02
White	1 [Reference]	...	1 [Reference]	...
Insurance type				
Public	1.71 (1.39–2.12)	<.001	1.21 (0.99–1.47)	.06
Other	1.61 (1.24–2.09)	<.001	1.18 (0.91–1.52)	.21
Private	1 [Reference]	...	1 [Reference]	...

Abbreviations: ACV, acute care visit; CI, confidence interval; OR, odds ratio.

^aUnadjusted odds ratios represent a bivariate relationship between historical acute care visits, age, race and insurance type, respectively, to future utilization.

^bAdjusted ORs include all listed variables in the table in the relationship.

High Users

Figure 3 shows the proportion of outpatient visits based on the number of historical ACVs. Seventy-five percent of outpatient visits had no historical ACVs, and 1.1% had 5 or more. Figure 3 also shows the mean number of future ACVs based on the historical visit count. Even though outpatient visits with 5 or more historical ACVs represented only 1.1% of the study sample, this group accounted for a higher mean number of future ACVs (mean, 3.7).

Validation of Model

The AUC from the final adjusted regression model was 0.749 (95% CI, 0.740–0.757), whereas the AUC from the cross-fold validation was 0.747 (95% CI, 0.739–0.755). On the basis of the AUC estimates and the precision of the CIs, the models were not significantly different. Furthermore, predicted probabilities between the 2 models were compared, with the absolute difference being nonsignificant (Δ , –0.000017; 95% CI, –0.000056 to 0.000021; root mean square error, 0.00328).

Discussion

In our study of pediatric patients with asthma, the historical count of asthma-related ACVs was predictive of future asthma-related ACVs. A significant increase in the probability of future ACVs was observed with each additional historical visit, effectively stratifying risk by the historical visit count. The predictive value of this simple model remained after adjusting for demographics, such as age, sex, race, and insurance status, reducing the likelihood of these variables confounding our results. This is particularly important for socioeconomic factors, such as race, given that black patients with asthma are known to have higher rates of ED visits and hospitalizations,⁹ and insurance status because the uninsured or those with public insurance generally experience higher rates of ED visits.¹⁰ Not only did our model effectively stratify the risk of future use, it also identified a very small proportion of outpatient visits (representing 74 individual patients) that accounted for a disproportionate number of future ACVs. This finding is similar to that of another study performed at our institution, in which 4% of

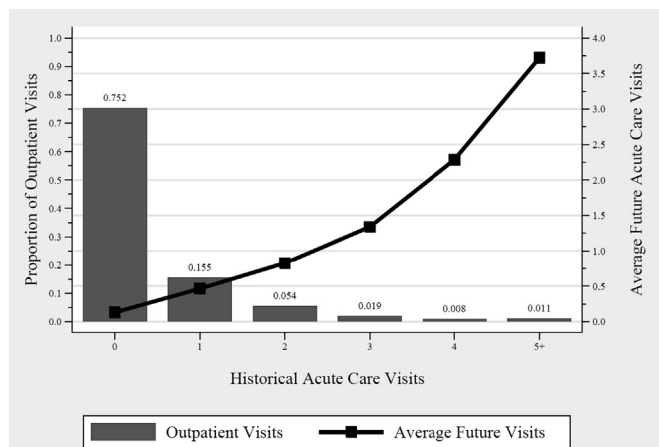


Figure 3. Proportion of outpatient visits by mean number of future asthma-related acute care visits in each historical acute care visit category.

patients accounted for approximately 20% of asthma-related ED visits and 1% of patients for approximately 20% of hospitalizations.¹¹

As noted previously, several studies have stratified pediatric patients with asthma for risk of future exacerbation and/or health care use. Greenberg et al³ developed a weighted Asthma Disease Activity Score (ADAS) in patients 15 years and older in the hopes of capturing multiple aspects of asthma into a single tool. The score incorporated the percent predicted forced expiratory volume in 1 second, quality-of-life assessment, nocturnal awakenings, peak expiratory flows, and rescue β -agonist use. The authors concluded that the ADAS was an accurate measure of disease activity and could predict the risk of an asthma exacerbation. A study by Forno et al² was developed in a cohort of Costa Rican children and included asthma symptoms, health care use, medical history, asthma medications, laboratory tests, and airway responsiveness. The score effectively stratified patients into risk categories, with low-risk patients having reduced odds (OR, 0.2; 95% CI, 0.1–0.3) and high-risk patients having greatly increased odds (OR, 8.3; 95% CI, 3.5–19.5) of a future asthma exacerbation when compared with average-risk patients. The model was also applied to a cohort of North American children, with a consistent effect seen, although attenuated.

Lieu et al⁴ used computer-based models to identify pediatric asthma patients at high risk for future ED visits and hospitalizations. Their model incorporated the following variables: having filled a prescription for oral corticosteroids, hospitalization in the past 6 months, not having a personal physician, use of more than one β -agonist unit per month, and 3 or more physicians prescribing asthma medications during the past 6 months. The number of past ED visits and the number of physicians prescribing asthma medications were associated with the highest relative risk of a future ED visit, whereas previous hospitalizations and one or more courses of oral corticosteroids were most predictive of a future hospitalization. A slightly different study by Schatz et al⁵ used administrative data from the Southern California Kaiser-Permanente Asthma Case Identification Database and included both pediatric and adult patients. Predictors included past hospitalization or ED visits, use of more than 14 β -agonist units, and use of systemic corticosteroids in the past 12 months. Patients in the high-risk group were 3 to 4 times more likely to have future ED visits or hospitalizations. Administrative data were also used in a study by Bennett et al,⁷ which classified high-risk patients based on the number of previous ambulatory visits, ED visits, and inpatient admissions, as well as prescriptions for oral corticosteroids. High-risk patients had significantly higher use than low-risk patients.

Most recently, a study by Bateman et al¹² validated a risk score for exacerbations, which identified patients at high risk of exacerbation based on predictive factors, such as short-acting β -agonist use, body mass index, Asthma Control Questionnaire (ACQ) score, and postbronchodilator forced expiratory volume in 1 second. Patients as young as 12 years were included; however, the mean age was 39.5 years, making it difficult to generalize the results to the pediatric population.

Although these and other previously reported predictive models have successfully stratified asthmatic patients for future risk of exacerbation or health care use, all incorporate multiple clinical parameters or extensive administrative data, limiting their practical use in most frontline and direct clinical care settings. In comparison, our study relies only on the single predictive variable of historical ACV count, which can easily be obtained from a medical record review, an administrative data query, or even report from the patient and family.

We note 2 studies similar to ours that used past asthma-related health care use to risk stratify patients. Taylor⁶ used the frequency of historical asthma-related ED visits to predict future ED visits and hospitalizations. As seen in our study, the risk of future visits increased with increasing number of historical visits. Specifically, in Taylor's study, patients with 3 or more historical ED visits were grouped into a single category. Of these patients, 52.7% had at least one future ED visit and 12.2% had at least one future admission. Furthermore, a historical ED visit count of 3 or more was associated with increased odds of a future ED visit (OR, 104.7) and future admission (OR, 107.6). The author noted little controversy in labeling these patients with 3 or more historical visits as "frequent fliers." We found a slightly higher probability for future ACVs with 3 or more historical ACVs (58%) but lower odds (adjusted OR, 11.89). Both the probability and odds of a future ACV continued to increase with 4 historical visits (75% probability; adjusted OR, 26.12) and 5 or more historical visits (87% probability; adjusted OR, 58.71), suggesting that patients with 3 or more visits cannot be grouped into a single category, given the significant increase in likelihood of future use. Taylor's study also differed from ours in that we incorporated historical UCC visits and inpatient admissions, in addition to ED visits, making our analysis more inclusive of all types of ACVs. In addition, future ACVs in our study included ED, UCC, and inpatient admissions, whereas Taylor included only ED visits and admissions. A study by Miller et al¹¹ also used historical ACVs but created a weighted score, assigning 2 points for a hospitalization and 1 point for an ED visit. In contrast, our study found no evidence to suggest that the type of ACV had a differential effect on risk of future use.

One limitation of our study is that our analysis is based on outpatient visits and not individual patients. That is, individual patients may have accounted for multiple outpatient visits during our study period. Nonetheless, we believe the model remains valid in its assessment of risk, despite this limitation. In addition, our study did not examine the duration of time between historical ACVs and the corresponding outpatient visit. Future studies should analyze whether historical visits occurring more recently (within 6 months) are of differing significance than more remote visits, relative to future use. Our study also involves a pediatric asthma population located in a large, metropolitan area with a significant percentage of minority patients with public health insurance, which may not be generalizable to other populations. Lastly, our analysis found that the type of ACV did not have a differential effect on the risk of future ACVs, which may not be consistent with other institutions or patient populations.

It is well demonstrated that reducing the burden of childhood asthma requires a coordinated, multidisciplinary approach that includes medication management and home-based interventions for asthma education and environmental control.^{8,13} Unfortunately,

economic resources for such services are limited, particularly for those that are home based, and coverage is not typical among public or commercial insurers. Determining which groups of patients receive these important interventions can be challenging, making a simple model such as ours a useful tool in prioritizing limited resources in a cost-effective manner. Furthermore, the finding that a small number of patients account for a disproportionate share of future use is significant when making population-based disease management decisions, as with those made by health care management and accountable care organizations, for investment in large-scale interventions. Finally, we hope that this model will also be a practical tool for clinicians to identify those asthmatic patients at high risk of future health care use so that appropriate referrals can be made to case management initiatives, group education efforts, home visitation programs, and mental health services. Future directions include implementing this model to identify patients who meet criteria for our institution's high-risk asthma protocol. Doing so will allow for prioritization of limited resources to those patients who need it most.

Acknowledgments

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