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A predictive model for identification of children at risk of subsequent high-frequency utilization of the emergency department for asthma

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Abstract

Background—Asthma is the most common chronic condition among children with high-frequency emergency department (ED) utilization. Previous research has shown in outpatients seen for asthma that acute care visits predict subsequent healthcare utilization. Among ED patients, however, the optimal method of predicting subsequent ED utilization remains to be described. The goal of this study was to create a predictive model to identify children in the ED who are at risk of subsequent high-frequency utilization of the ED for asthma.

Methods—We used three years of data, 2013–2015, drawn from the electronic health records at a tertiary care, urban, children's hospital that is a high-volume center for asthma care. Data were split into a derivation (50%) and validation/test (50%) set, and three models were created for testing: (1) All index patients; (2) Removing patients with complex chronic conditions; (3) Subset of patients with in-network care on whom more clinical data were available. Each multivariable model was then tested in the validation set, and its performance evaluated by predicting error rate, calculation of a ROC curve and identification of the optimal cutpoint to maximize sensitivity and specificity.

Results—There were 5535 patients with index ED visits of whom 2767 were in the derivation set and 2768 in the validation set. Of the 5535 patients, 125 patients (2.3%) had 4 visits for asthma in the outcome year. Significant predictors in models 1 and 2 were age and number of prior ED visits for asthma. For model 3 (additional clinical information available), the predictors were number of prior ED visits for asthma, number of primary care visits, and not having a controller

medication. Areas under the ROC curve were 0.77 for Model 1, 0.80 for Model 2 and 0.77 for Model 3.

Conclusion—Administrative data available at the time of ED triage can predict subsequent high utilization of the ED, with areas under the ROC curve of 0.77–0.80. The addition of clinical variables did not improve the model performance. These models provide useful tools for researchers interested in examining intervention efficacy by predicted risk group.

Introduction

Approximately 10.5 million children have been diagnosed as having asthma¹, and together account for over 600,000 ED visits annually.² The rate of ED visits for asthma increased by 13.3% from 2001 to 2010.³ Among children with 4 or more ED visits in a year, asthma is the most common diagnosis.⁴ In addition, adult data suggest that patients with frequent visits to the ED can account for up to 57% of the cost of asthma care.⁵ Despite frequent contact with the medical system, high frequency utilization of the ED for asthma is associated with worse knowledge of asthma care and of medication use.⁶ In current clinical practice, however these children are only identified after the pattern of utilization has already occurred.

Studies have shown that prior ED utilization for asthma is associated with future utilization.^{7,8,9} In particular, among outpatients seen for asthma, the number of previous acute care visits (ED, urgent care or inpatient settings) predicted subsequent healthcare utilization.¹⁰ Patients with 5 or more acute care visits accounted for only 1.1% of the sample, but had an adjusted odds ratio (aOR) of 59 (95% CI, 24–142) for a future acute care visit.¹⁰ However, the Hanson model was limited to patients who were seen for asthma at an outpatient visit, and combined ED visits, urgent care and admission. As many asthma interventions require intensive contact with patients and families^{11,12}, an ED-specific predictive model to risk-stratify patients would allow for the testing of ED-initiated interventions by risk group and the eventual targeting of interventions toward ED patients who are more likely to obtain benefit from the intervention.

The goal of this study was to create a predictive model to identify children in the ED who are at risk of subsequent high-frequency utilization of the ED for asthma.

Methods

Data

We used three years of deidentified data, from September 1, 2012 to August 31, 2015, drawn from the electronic health records at a tertiary care, urban children's hospital that is a high-volume center for asthma care. This structure reduces the potential for seasonal variation or misinterpretation of utilization patterns within a single year, and the potential for confounding by multiple episodes within a short frame of time for a single acute illness. It also allows for the testing of the predictive value of the model, despite the use of retrospective data, since the outcomes are drawn from the year after the predictors.

Patients were eligible for inclusion if they had a visit for asthma [CD 9 codes 493.00 through 493.92] in the index year (Year 2). Year 1 (predictor year: Sept. 2012-Aug. 2013) was used to assess prior utilization for asthma (frequency, utilization and disposition) as well as primary care provider and specialty utilization. Year 2 (index year: Sept 2013-Aug 2014) was the source of the demographic data for the model. Year 3 (outcome year: Sept 2014-Aug 2015) was the source of data on frequency of ED utilization for asthma.

Table 1 describes the pre-specified candidate predictor variables. Patients with any primary care visit in our health system in year 1 were considered to have in-network primary care; similarly those with any pulmonary or allergy subspecialty clinic visit within year 1 were considered to have in-network specialty care. The ED routinely assigns triage acuity (ESI) to each visit, which was abstracted from the EMR. Race/ethnicity were abstracted from the demographic data entered during the registration process and were categorized as Hispanic, non-Hispanic white and non-Hispanic black. Information about controller medications and asthma action plans were abstracted from the index visit EHR; asthma severity level was abstracted from the problem list. High-frequency utilization was defined as ≥ 4 ED visits for asthma in outcome year. The protocol was reviewed by the Children's Hospital of Philadelphia Institutional Review Board and determined to be exempt (IRB 15–012587).

Statistical analysis

We created three models for testing. The first was the baseline model including all index patients in the modeling data set. The second removed the patients with complex chronic care conditions¹³ whose reasons for frequent return visits may be different from the overall cohort. Lastly, we examined a more detailed clinical model in the subset of patients who had in-network care, on whom we had more detailed clinical data.

Data splitting technique was used to validate the fitted models. Patients were split into two parts: 50% to develop the model (derivation set) and 50% to measure its performance (test set). In the derivation set, descriptive statistical analysis was conducted using inferential and graphical techniques with calculation of standard summary statistics. Logistic regression models were used to determine the associations between predictors (Table 1) and high frequency utilization.

Sensitivity analysis was used to assess data points that are outliers and/or influential. Hosmer-Lemeshow goodness-of-fit test and specification link test were performed to assess the adequacy of the logistic models. A multivariable model was developed starting with inclusion of variables felt to be clinically relevant, and then using backwards selection ($p < 0.10$) in the derivation set. The final multivariable model was then tested in the validation set, and its performance evaluated by predicting error rate, calculation of a ROC curve and identification of the optimal cutpoint to maximize sensitivity and specificity.

Results

There were 5535 patients with index ED visits of whom 2767 were in the derivation set and 2768 in the validation set. Of the 5535 patients, 125 patients (2.3%) had ≥ 4 visits for asthma in the outcome year. 2491 (45%) had in-network primary care and 674 (12.2%) had in-

network specialty (pulmonary or allergy) care. 127 children (3.1%) had complex chronic care conditions. Table 2 describes the demographics and baseline characteristics of the cohort.

Derivation Set

All of the models had Homer and Lemeshow Goodness-of-Fit test results indicating that the models fit well (Model 1 $p=0.27$; Model 2 $p=0.35$; Model 3 $p=0.79$). In the administrative data models (1 and 2), increasing age was associated with decreased risk of high frequency utilization, and increasing number of predictor year visits was associated with an increased risk. In the clinical model, age was no longer significantly associated but an increased number of primary care visits had a slight association with increasing risk of high-frequency ED utilization. Absence of a controller medication was very strongly associated with increased risk of high frequency ED utilization for asthma (Table 3).

Validation Set

Areas under the ROC curve were 0.77 for Model 1, 0.80 for Model 2 and 0.77 for Model 3. For Model 1 [EST= $-0.06 \times \text{age} + 0.4 \times \text{prior ED visits for asthma}$] the cutpoint of EST = 0 yielded a sensitivity of 66%, specificity of 73%, positive likelihood ratio (LR+) of 2.5 and negative likelihood ratio (LR-) of 0.5. Figure 1 shows the ROC curve for Model 1 and Table 4 shows the number of children who would be classified correctly or incorrectly by the model. Model 2 had similar performance [EST= $-0.05 \times \text{age} + 0.42 \times \text{prior ED visits for asthma}$]. With a cutpoint of EST = 0, it had a sensitivity of 68%, specificity of 70%, LR+ of 2.3 and LR- of 0.45.

For Model 3 [EST= $0.42 \times \text{prior ED visits for asthma} + 0.08 \times \text{primary care visits} + 0.74 \times \text{controller medication}$], a cutpoint of EST = 1.25 resulted in a sensitivity of 73%, specificity of 66%, LR+ of 2.1 and LR- of 0.4. Table 5 shows the classification of children in the validation set using Model 3.

Discussion

We derived and validated predictive models for high frequency ED utilization over the year following a presentation to the pediatric ED with an asthma exacerbation. The combination of demographic, clinical and utilization variables available at the time of index visit predicted subsequent high-frequency (≥ 4 visits/year)⁴ ED utilization for asthma with areas under the ROC curve of 0.77 to 0.80. Using our selected cut-points, sensitivities ranged from 66 to 72%. In Model 1, using only administrative data, only 21 children out of a sample of 2768 (0.8%) would have been false negatives (predicted to have low utilization, actual high utilization). In Model 3, with the addition of the clinical data, 9/1277 children or 0.7% would have been false negatives.

Similar to prior work in the outpatient setting,¹⁰ the number of previous visits was a strong predictor of utilization across all three models. Because our center has a strong primary care network, with data in the same electronic medical record, we were able to investigate the independent effects of specific elements of asthma care in predicting high frequency utilization. Interestingly, most of the utilization variables (specialty care, missed visits) were

not significant predictors in the multivariable model nor was an asthma action plan, and only primary care visits and controller medication remained significant. The association between increasing numbers of primary care visits and increasing ED visits may represent a population of patients with a different threshold for seeking care, increased disease severity that was unmeasured by our other asthma measures, or unmet social needs that hinder ability to adhere to treatment and management plans. The role of long-term control medication use in reducing asthma exacerbations is well described,¹⁴ but these findings serve to emphasize its importance in reducing the burden of ED visits on patients and families.

Overall, these results suggest that children at risk of future high-frequency utilization for asthma can be identified at an index ED visit. Although the model performance is not perfect, it could provide useful information to identify patients and families in need of additional resources. A recent article by Johnson et al. states “Improved predictive modeling should aim not only to identify individuals who are likely to experience sustained levels of avoidable utilization, but also to better classify subgroups of patients for whom aligned interventions are needed.”¹⁵ As many asthma interventions require intensive contact, predictive models to risk-stratify patients can enable the testing of ED-initiated interventions by risk group, and the eventual targeting toward ED patients who are most likely to obtain benefit from the intervention.

Limitations

The study has a few limitations. First, as we used only de-identified data, we do not have the date of ED visit or return visit, and so we are unable to address time between visits. Secondly, the time frame for the outcomes is visits in the subsequent year. This avoids the problem of visits clustering around the index visit (4 visits in 4 days), which may represent an acute illness rather than a pattern of behavior. However, because we are examining the subsequent calendar year for the outcome (rather than 365 days from the index visit), the predictive power of our model may be reduced, as the outcome is further temporally from the predictors. Additionally, data were abstracted from the electronic medical record, and are dependent on the accuracy of provider entry and assessment of asthma severity. Finally, a significant limitation of this study is that we are only able to capture return visits back to our single center, which may undercount overall utilization. We are therefore planning a validation study to test the model in multi-center data.

Conclusion

Using limited data available at the time of triage, subsequent high utilization of the ED for asthma can be predicted with areas under the ROC curve of 0.77–0.80. The addition of clinical variables did not markedly improve the model performance. These models provide useful tools to researchers interested in examining intervention efficacy by predicted risk group to support the eventual deployment of interventions in the groups most likely to benefit.

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Figure 1:
Receiver operating characteristic curve for baseline model using all patients (model 1).

Table 1:

Pre-specified candidate predictor variables

Analysis	Candidate predictor variables
Full analysis (Models 1 and 2)	In-network primary or specialty asthma care Age ED triage acuity (ESI) Race/ethnicity Insurance Gender Season Shift/time of presentation Day of week Number of ED visits in predictor year Number of ED asthma visits in predictor year Number of ED asthma visits with ESI 4 or 5 in predictor year Number of ED asthma visits resulting in admission in predictor year Number of ED asthma visits resulting in observation in predictor year
Subset: In-network care (Model 3)	Location of primary care Prescribed rescue medications Prescribed controller medication Asthma action plan Number of primary visits Number of (pulmonary or allergy) specialty visits Missed primary visits Missed (pulmonary or allergy) specialty visits Asthma severity level

Table 2:

Demographics and baseline characteristics

		<4 Visits in Outcome Year (n=5410)		4 Visits in Outcome Year (n=125)		P value
		Mean	SD	Mean	SD	
Age (years)		6.3	4.8	5.2	4.9	0.01
		Number	%	Number	%	
Gender	Female	2237	41.4	54	43.2	0.71
	Male	3173	58.7	71	56.8	
Race	Hispanic	341	6.3	5	4	<0.01
	Non-Hispanic Black	4174	77.2	114	91.2	
	Non-Hispanic White	562	10.4	4	3.2	
	Other	333	6.2	2	1.6	
Insurance	Medicaid	3726	68.9	108	86.4	<0.01
	Private	1469	27.2	14	11.2	
	Self-pay	215	3.4	3	2.4	
ESI	1	271	5	8	6.4	0.41
	2	1809	33.5	51	40.7	
	3	1838	34	36	28.8	
	4	1312	24.3	26	20.8	
	5	172	3.2	4	3.2	
Season	Spring	1406	26	19	15.2	<0.01
	Summer	763	14	13	10.4	
	Fall	1835	33.9	67	53.6	
	Winter	1406	26	26	20.8	
Time of presentation	12am-7:59am	795	14.7	23	18.4	0.38
	8am-3:59pm	2312	42.7	47	37.6	
	4pm-11:59am	2303	42.6	55	44	
Day of week	Sunday	834	15.4	17	13.6	0.64
	Monday	857	15.8	25	20	
	Tuesday	840	15.5	14	11.2	
	Wednesday	772	14.3	17	13.6	
	Thursday	722	13.4	20	16	
	Friday	695	12.9	14	11.2	
	Saturday	690	12.8	18	14.4	
Asthma action plan	No	3503	64.8	70	56	0.05
	Yes	1907	25.3	55	44	
Asthma severity	Intermittent	485	9	10	8	<0.01
	Mild persistent	323	6	6	4.8	
	Moderate persistent	191	3.5	11	8.8	

		<4 Visits in Outcome Year (n=5410)		4 Visits in Outcome Year (n=125)		P value
		Mean	SD	Mean	SD	
	Severe persistent	26	0.5	4	3.2	
	Unable to classify	4385	81.1	94	75.2	
Rescue medication	No	1484	27.4	28	22.4	0.22
	Yes	3926	75.6	97	77.6	
Controller medication	No	2806	51.9	52	41.6	0.02
	Yes	2604	48.1	73	58.4	
In-network primary care	No	2978	55	66	52.8	0.65
	Yes	2432	45	59	47.2	
Complex chronic conditions	No	5240	96.9	123	98.4	0.44
	Yes	170	3.1	2	1.6	
		Mean	SD	Mean	SD	
Number of ED visits in predictor year		1.4	1.9	3.6	4	<0.01
Number of ED asthma visits in predictor year		0.6	1.1	2	2.6	<0.01
Number of ED asthma visits with ESI 4 or 5 in predictor year		0.1	0.5	0.4	0.9	<0.01
Number of ED asthma visits resulting in admission in predictor year		0.2	0.6	0.6	1.1	<0.01
Number of ED asthma visits resulting in observation in predictor year		0.1	0.3	0.2	0.6	0.07
Number of primary care visits in predictor year		1.8	3.0	2.8	4.8	0.02
Number of pulmonary or allergy visits in predictor year		0.3	1.3	0.4	1.4	0.19
Number of missed primary visits in predictor year		0.4	1.1	0.8	1.6	0.03
Number of missed specialty visits in predictor year		0.1	0.4	0.2	0.7	<0.01

Table 3:

Final multivariable models for each modeling strategy

Model	Variable	Odds ratio	95% Confidence interval	p-value
1 Baseline	Age	0.94	0.89-1.001	0.054
	Number of prior ED visits for asthma	1.49	1.32-1.68	<0.0001
2 Removed children with complex chronic conditions	Age	0.95	0.89-1.01	0.084
	Number of prior ED visits for asthma	1.52	1.23-1.71	<0.0001
3* In-network care	Number of prior ED visits for asthma	1.54	1.28-1.86	<0.0001
	Number of primary care visits	1.09	1.001-1.18	0.047
	Not having controller medication	4.43	1.65-11.89	0.003

* As this model only includes derivation set patients with in-network primary care total, n=1214

Table 4:

Validation set performance of baseline model (Model 1)

	High frequency utilization of the ED in outcome year		
	No	Yes	Total
EST<0 (Predicted negative)	1992	21	2013
EST ≥ 0 (Predicted positive)	714	41	755
Total	2706	62	2768

Table 5:

Validation set performance of in-network care model (Model 3)

	High frequency utilization of the ED in outcome year		
	No	Yes	Total
EST<1.25 (Predicted negative)	820	9	829
EST ≥ 1.25 (Predicted positive)	424	24	448
Total	1244	33	1277