Factors associated with aeroallergen testing among adults with asthma in a large health system

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Background: Aeroallergen testing informs precision care for adults with asthma, yet the epidemiology of testing in this population remains poorly understood.

Objective: We sought to identify factors associated with receiving aeroallergen testing, the results of these tests, and subsequent reductions in exacerbation measures among adults with asthma.

Methods: We used electronic health record data to conduct a retrospective, observational cohort study of 30,775 adults with asthma who had an office visit with a primary care provider or an asthma specialist from January 1, 2017, to August 26, 2022. We used regression models to identify (1) factors associated with receiving any aeroallergen test and tests to 9 allergen categories after the index visit, (2) factors associated with positive test results, and (3) reductions in asthma exacerbation measures in the year after testing compared with before testing.

Results: Testing was received by 2201 patients (7.2%). According to multivariable models, receiving testing was associated with having any office visit with an allergy/immunology specialist during the study period (odds ratio [OR] = 91.3 vs primary care only [$P < .001$]) and having an asthma emergency department visit (OR = 1.62 [$P = .004$]) or hospitalization (OR = 1.62 [$P = .03$]) in the year before the index visit. Age 65 years or older conferred decreased odds of testing (OR = 0.74 vs age 18-34 years [$P = .008$]) and negative test results to 6 categories ($P \leq .04$ for all comparisons). Black race conferred increased odds of testing (OR =1.22 vs White race [$P = .01$]) and positive test results to 8 categories ($P < .04$ for all comparisons). Exacerbation measures decreased after testing.

Conclusion: Aeroallergen testing was performed infrequently among adults with asthma and was associated with reductions in asthma exacerbation measures. (J Allergy Clin Immunol Global 2023;2:100167.)

Key words: *Asthma, aeroallergen testing, asthma exacerbations, electronic health record, epidemiology*

Asthma affects 8% of adults and accounts for 170,000 hospitalizations, 1.8 million emergency department (ED) visits, and $80 billion in health care expenditures annually in the United States.[1-3] Addressing modifiable risk factors for asthma symptoms and exacerbations, including allergen exposure among sensitized patients, is a key component of asthma care.[2,4] Allergies to dust mite,[5-9] cat,[4,10] dog,[4,10] mold,[11-17] cockroach,[8,18,19] rodent,[20] grass,[21-24] and ragweed[25,26] represent common asthma triggers, although some allergens disproportionately affect residents of urban areas, where asthma morbidity is high.[8,27-30] A positive allergy testing result informs precision care by clarifying an allergic asthma phenotype,[31-36] contributing to patient education on the role of allergens in triggering asthma symptoms,[27] targeting home-based interventions to reduce allergen exposure,[2,27,37] and enabling pharmacotherapy for allergic asthma.

The National Asthma Education and Prevention Program clinical guidelines recommend testing to indoor aeroallergens for persons with persistent asthma—defined as asthma that is uncontrolled or requires controller treatment to maintain control—who are exposed to indoor allergens.[27] As 70% of people with asthma have persistent asthma,[27] and most US homes have elevated levels of 1 or more aeroallergens,[38] the guidelines estimate that 50% of people with asthma should be tested.[27] However, 1 study of adults with persistent asthma in primary care practices found that only 28% had an allergy assessment and 1% had documented aeroallergen test results.[39] In this study, we sought to identify factors associated with receiving new aeroallergen tests and the results of these tests, as well as to evaluate reductions in asthma exacerbation measures after testing, in adults with asthma by using electronic health record (EHR) data from a large, multihospital health system.

METHODS

Study design

We conducted a retrospective, observational cohort study of adults with asthma using codified EHR data from January 1, 2015, to August 26, 2022. We created multivariable regression models to identify factors associated with (1) the receipt of aeroallergen testing after an initial office visit from January 1, 2017, to August 26, 2022, and (2) positive test results. Among patients who received

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Abbreviations used
ADI: Area Deprivation Index
COVID-19: Coronavirus disease 2019
ED: Emergency department
EHR: Electronic health record
ICS: Inhaled corticosteroid
LABA: Long-acting β-agonist
LAMA: Long-acting muscarinic antagonist
OCS: Oral corticosteroid
OR: Odds ratio

this testing before August 26, 2021, we used logistic regression models to evaluate the unadjusted reductions in asthma exacerbation measures (details of these measures are provided later in this section) after the test date versus before. Fig 1 and Fig E1 (in the Online Repository at www.jaci-global.org) provide an overview of the study design and time line of data collection, respectively. More extensive methods are provided in the Supplementary Methods in the Online Repository (at www.jaci-global.org).

Study population

Our study population was based on data extracted from EHRs from Penn Medicine, which is a large, diverse health system serving the Greater Philadelphia Area. We obtained patient-level codified data and clinical notes for adults (ie, age ≥ 18 years) who had at least 1 encounter with an *International Classification of Diseases, 10th Revision*, code for asthma (J45*) in any of their records; had 1 or more outpatient visits in the departments of internal medicine, family medicine, allergy/immunology, or pulmonary from January 1, 2017, to August 26, 2022; and received at least 1 inhaled corticosteroid (ICS) prescription after the index visit, which was the earliest visit after January 1, 2017. We excluded patients who (1) had codified documentation of aeroallergen testing performed from January 1, 2015, until the index visit; (2) were prescribed allergen immunotherapy from January 1, 2015, until the index visit according to codified procedure or prescription data, as these patients were assumed to have had prior aeroallergen testing; or (3) resided outside Pennsylvania, New Jersey, New York, or Delaware.

Clinic variables

We created 2 variables to account for the clinics at which primary care and asthma specialist encounters took place: (1) the index visit clinic site was the uniquely named site at which the patient's first outpatient encounter in a qualifying department occurred and (2) the specialist visit category was classified according to the department name(s) of the encounters: primary care only, pulmonary (ie, pulmonary encounter(s) with or without primary care encounters), or allergy/immunology (ie, any allergy/immunology encounters).

ADI

An Area Deprivation Index (ADI) value was assigned to each person as a geographic area measure of his or her social vulnerability (where 1 is the lowest and 100 the highest vulnerability) and categorized into 4 groups: 1-25, 26-50, 51-75, and 76-100.

Asthma exacerbation measures

We selected 3 variables to represent asthma exacerbations: oral corticosteroid (OCS) bursts, ED visits, and hospitalizations. We considered exacerbation measures during 3 time periods: the 12-month baseline period (ie, before the index visit) as well as the 12-month periods before and after aeroallergen testing. More details are provided in the Supplementary Methods in the Online Repository, and lists of the ICD-10 codes and chief complaints used to define ED visits and hospitalizations are provided in Table E1.

Aeroallergen test data

We defined the outcome of aeroallergen testing as any skin prick or serum aeroallergen tests that were ordered, performed, and documented (using codified EHR fields) during the period extending from after the index visit to August 26, 2022. More details are provided in the Supplementary Methods in the Online Repository, and lists of allergy test names are shown in Table E2.

Aeroallergen test results

Skin prick test panels were categorized as having adequate positive and negative controls, and skin prick and serum tests were categorized as positive or negative according to criteria in the 2008 Allergy Diagnostic Testing Updated Practice Parameter.[40]

Controller inhaler data

We identified inhaler prescription data generated during the period extending from after the index visit until August 26, 2022 and categorized these into 3 groups: (1) ICS prescription(s) only, (2) any ICS/long-acting β-agonist (LABA) prescription(s), and (3) any ICS/LABA plus a long-acting muscarinic antagonist (LAMA) prescription(s) as a combined triple inhaler or a separate LAMA prescription.

Allergen immunotherapy variables

We identified the dates of administration of subcutaneous allergen immunotherapy by using the documented Current Procedural Terminology codes of 95115, 95117, and 95165 during the period from January 1, 2015, to August 26, 2022, as well as the dates of administration of sublingual allergen immunotherapy tablets during the period from January 1, 2015, to August 26, 2022.

Documentation of aeroallergen testing according to noncodified data

An allergy/immunology specialist performed EHR chart review of 300 full charts, selected at random, of patients categorized as not receiving aeroallergen testing according to the codified data for evidence of aeroallergen testing according to noncodified data. A second reviewer, who was an allergy/immunology fellow, reviewed 100 of these charts to assess the interrater reliability.

Statistical analysis

STATA, version 16.1, was used for analyses. Bivariate associations of patient demographic factors (eg, age, sex, and race), comorbidity data (eg, chronic obstructive pulmonary

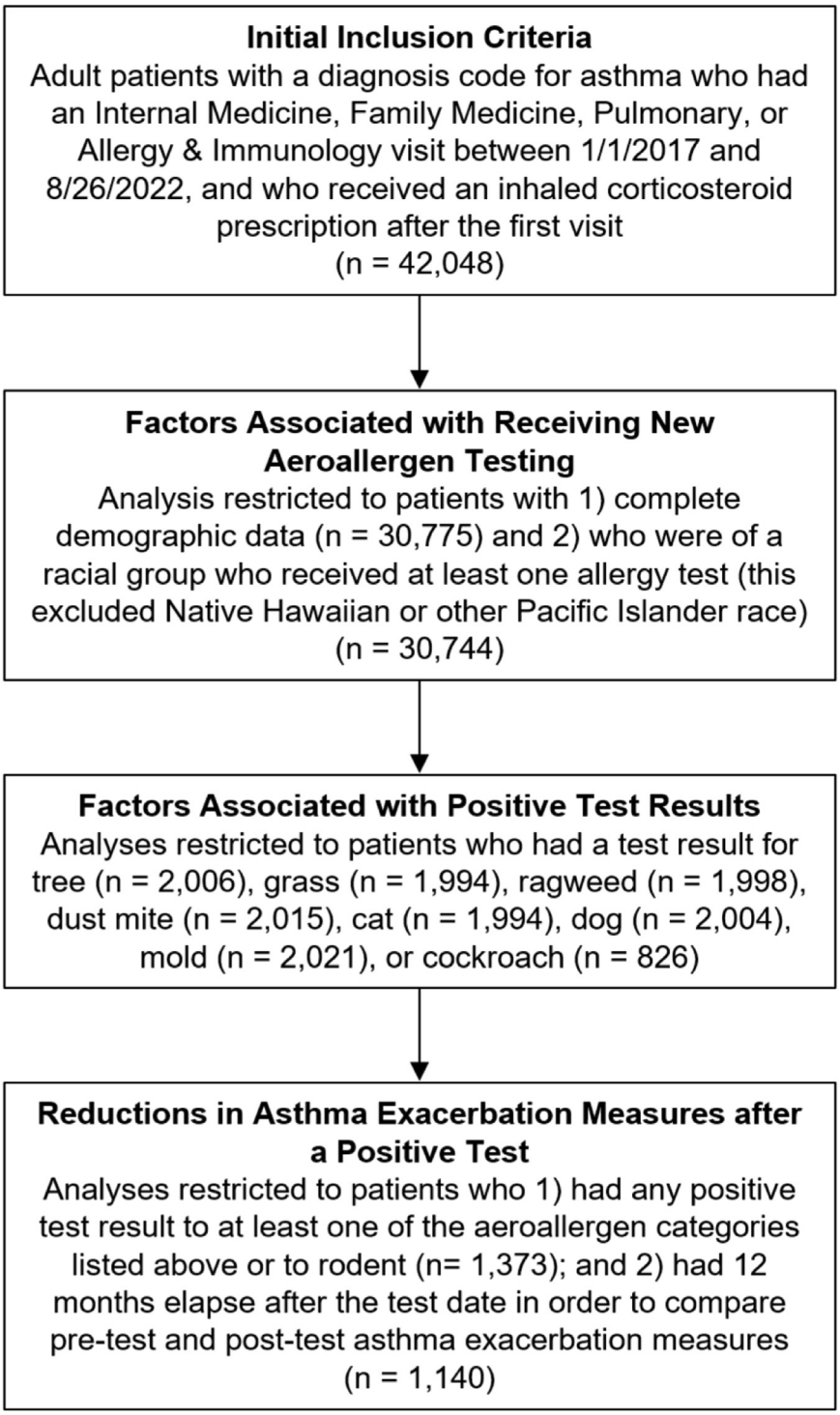

FIG 1. Overall study design. Shown are the different groups of patients used for specific analyses, along with the corresponding selection criteria.

disease), controller inhaler category, baseline exacerbation measures, and specialist visit category with the outcome of receiving aeroallergen testing after the index visit were evaluated by using the Pearson chi-square tests. Bivariate associations of patient demographic factors with having complete demographic data versus any missing data, as well as for the outcome of having had testing versus no testing for the 300 patients who underwent validation by chart review, were evaluated by using the Pearson chi-square tests. We then created a multivariable logistic regression model with receiving testing to any of the 9 aeroallergen categories as the outcome, as well as the patient demographic factors, comorbidities, controller inhaler variable, baseline

exacerbation measures, and specialist visit category included as independent variables, and with the index visit clinic site modeled as a random intercept. For this model, we assessed collinearity among the independent variables by computing variance inflation factors. To identify factors associated with receiving tests to each aeroallergen category, we created 9 multivariable logistic regression models in which receiving a test to each category was the outcome; the same independent variables used for the outcome of receiving testing to any category were included in each model. For patients who had test results for all 9 categories, we computed the correlation coefficients of positive test results between categories. To identify factors associated with positive test results to each category, we created multivariable logistic regression models, with having a positive test result to each category as the outcome, the same independent variables used for the outcome of receiving testing to any category, and an additional independent variable for test modality (ie, any skin prick testing or serum testing only). To evaluate the reductions in the number of OCS bursts, asthma ED visits, and asthma hospitalizations in the 12-month period after a positive test result, we created 3 ordinal logistic regression models, with each exacerbation measure in the 12-month period after a positive testing result used as an outcome and the same measure in the 12-month period before testing used as an independent variable, after which we calculated the probabilities of a pre-post reduction in the measure by using postestimation tests. We repeated these ordinal logistic regression analyses for all tested patients irrespective of their test results and again for patients with only negative test results.

RESULTS

Patient characteristics

Of the 42,048 patients who met inclusion criteria, 30,775 (73.2%) had complete data for all demographic variables and the ADI. The characteristics of these patients are shown in Table I. Compared with patients who did not receive aeroallergen testing, the 2,201 patients (7.2%) who received testing were more likely to be younger than 45 years ($P < .001$), be female ($P < .001$), be of Black race ($P < .001$), have Medicaid insurance ($P < .001$), have an ADI higher than 50 ($P = .002$), have received a prescription for an ICS/LABA and LAMA ($P < .001$), and have had 1 or more OCS bursts ($P < .001$) or 1 or more asthma ED visits ($P < .001$) or hospitalizations ($P < .001$) in the 12 months before the index visit. When testing after the coronavirus disease 2019 (COVID-19) lockdown date of March 17, 2020, in Philadelphia was compared with testing before the lockdown date, it was found that the numbers of skin and serum tests initially declined, after which serum tests rebounded while numbers of skin tests remained low (see Fig E2 of the Online Repository at www.jaci-global.org). When skin and serum tests were considered together, testing rates declined after the lockdown date: Among the 26,968 patients with a clinic visit before that date, 1,336 (5.0%) received testing before that date, whereas after the lockdown date, 865 of the remaining 29,439 patients (2.9%) received testing. Overall, 50% of allergy/immunology patients (1,171 of 2,341) were tested, representing 53.2% of all tested patients; whereas 1.2% of patients in the primary care–only category (212 of 17,517) were tested, representing 9.6% of all tested patients. Patients with missing demographic data (n = 11,273) were more likely to be aged 18 to 34 years ($P < .001$), be male ($P < .001$), be of White race ($P < .001$) and not have Medicare insurance ($P < .001$ [Table E3]).

Of the 2,201 patients who received testing, 1,511 (68.7%) received only serum testing and 690 (31.3%) received any skin prick testing. The ratios of skin tests to serum tests were 504:910 (0.55) before the COVID-19 lockdown date and 164:730 (0.22) after this date. The mean number of aeroallergen categories tested per person was 6.9 of 9 (SD = 1.96). Of the 1,373 patients who had a positive test result, 71 (5.2%) were prescribed omalizumab, 67 (4.9%) received subcutaneous immunotherapy, and 7 (0.5%) received sublingual immunotherapy after the index visit. The correlation matrix of positive test results for the 306 patients with test results in all 9 categories showed moderately positive correlations between categories (see Fig E3 of the Online Repository at www.jaci-global.org): the highest correlations were for tree and grass (0.55), tree and ragweed (0.65), grass and ragweed (0.66), and cat and dog (0.71).

Missing aeroallergen testing documentation

Among the 300 patients who were classified as not receiving aeroallergen testing according to codified data, 66 (22%) were found to have had testing reported after full chart review, and 28 of these 66 had documented results in their charts with the testing performed less than 5 years before the index visit through August 26, 2022. More details are provided in the Supplementary Results (see the Online Repository at www.jaci-global.org).

Factors associated with receiving aeroallergen testing

Of the 30,775 patients with complete demographic data, 30,744 (99.9%) were of a racial group whose members received at least 1 aeroallergen test (ie, this excluded individuals of the Native Hawaiian or other Pacific Islander races) and were included in the multivariable analysis of factors associated with receiving any testing. According to this analysis, the specialist visit category was the most important determinant of receiving testing: Having a pulmonary or allergy/immunology visit compared with receiving primary care only was associated with higher odds of testing (odds ratio [OR] = 7.08 and 91.3, respectively [$P < .001$]; Table II). In addition, the following characteristics were associated with higher odds of receiving testing: being of the Black race (OR = 1.22 vs being of the White race [$P = .01$]); receiving a prescription for an ICS/LABA (OR = 1.36 vs ICS only [$P < .001$]); receiving a prescription for an ICS/LABA and LAMA (OR = 2.66 vs ICS only [$P < .001$]); and having 1 or more asthma ED visits (OR = 1.62 vs none [$P = .004$]) or hospitalizations (OR = 1.62 vs [none $P = .03$]) in the year prior to the index visit. Age 65 years or older (OR = 0.74 vs age 18-34 [$P = .008$]) and current smoking (OR = 0.75 vs never [$P = .002$]) were associated with decreased odds of testing. The variance inflation factors were less than 1.8 for all variables, indicating minimal collinearity (see Table E5 of the Online Repository at www.jaci-global.org). The results of the analyses of factors associated with receiving tests to each of the 9 aeroallergen categories are shown in Fig 2 and Tables E6 and E7 (see the Online Repository at www.jaci-global.org).

Factors associated with positive aeroallergen test results

Among the 2201 patients who received testing, at least 1994 (90.6%) received tests to tree, grass, ragweed, dust mite, cat, dog,

TABLE I. Patient and provider characteristics related to aeroallergen testing

Characteristic	Overall (N = 30,775)	No aeroallergen testing (n = 28,574)	Aeroallergen testing (n = 2,201)	*P* value
Age (y)				<.001
18-34	6,305 (20.5%)	5,769 (20.2%)	536 (24.4%)	
35-44	4,505 (14.6%)	4,127 (14.4%)	378 (17.2%)	
45-54	5,661 (18.4%)	5,265 (18.4%)	396 (18.0%)	
55-64	6,711 (21.8%)	6,248 (21.9%)	463 (21.0%)	
≥65	7,593 (24.7%)	7,165 (25.1%)	428 (19.4%)	
Sex				<.001
Male	9,109 (29.6%)	8,551 (29.9%)	558 (25.4%)	
Female	21,666 (70.4%)	20,023 (70.1%)	1,643 (74.6%)	
Race				<.001
American Indian or AN	100 (0.3%)	83 (0.3%)	17 (0.8%)	
Asian	1,068 (3.5%)	960 (3.4%)	108 (4.9%)	
Black	9,891 (32.1%)	9,096 (31.8%)	795 (36.1%)	
Native Hawaiian or other PI	31 (0.1%)	31 (0.1%)	0 (0%)	
White	19,685 (64.0%)	18,404 (64.4%)	1,281 (58.2%)	
Ethnicity				.01
Not Hispanic or Latino	30,323 (98.5%)	28,168 (98.6%)	2,155 (97.9%)	
Hispanic or Latino	452 (1.5%)	406 (1.4%)	46 (2.1%)	
Insurance status				<.001
Commercial	159,91 (52.0%)	14,854 (52.0%)	1,137 (51.7%)	
Medicaid	5,122 (16.6%)	4,644 (16.3%)	478 (21.7%)	
Medicare	9,662 (31.4%)	9,076 (31.8%)	586 (26.6%)	
ADI				.002
1-25	11,473 (37.3%)	10,695 (37.4%)	778 (35.3%)	
26-50	8,961 (29.1%)	8,357 (29.2%)	604 (27.4%)	
51-75	4,538 (14.7%)	4,192 (14.7%)	346 (15.7%)	
76-100	5,803 (18.9%)	5,330 (18.7%)	473 (21.5%)	
BMI				.17
Normal	7,384 (24.0%)	6,824 (23.9%)	560 (25.4%)	
Overweight	8,710 (28.3%)	8,085 (28.3%)	625 (28.4%)	
Class I obesity	6,629 (21.5%)	6,181 (21.6%)	448 (20.4%)	
Class II obesity	4,050 (13.2%)	3,783 (13.2%)	267 (12.1%)	
Class III obesity	4,002 (13.0%)	3,701 (13.0%)	301 (13.7%)	
Smoking category				<.001
Never	17,512 (56.9%)	16,189 (56.7%)	1,323 (60.1%)	
Former	8,828 (28.7%)	8,184 (28.6%)	644 (29.3%)	
Current	4,435 (14.4%)	4,201 (14.7%)	234 (10.6%)	
COPD	6,473 (21.0%)	5,929 (20.7%)	544 (24.7%)	<.001
Nasal polyposis	1,044 (3.4%)	881 (3.1%)	163 (7.4%)	<.001
Rhinitis	18,217 (59.2%)	16,342 (57.2%)	1,875 (85.2%)	<.001
Controller inhaler category				<.001
ICS only	7,876 (25.6%)	7,530 (26.4%)	346 (15.7%)	
ICS/LABA	18,641 (60.6%)	17,380 (60.8%)	1,261 (57.3%)	
ICS/LABA and LAMA	4,258 (13.8%)	3,664 (12.8%)	594 (27.0%)	
OCS bursts in the year before the first office visit				<.001
0	24,240 (78.8%)	22,656 (79.3%)	1,584 (72.0%)	
1	4,516 (14.7%)	4,131 (14.5%)	385 (17.5%)	
2-3	1,635 (5.3%)	1,467 (5.1%)	168 (7.6%)	
≥4	384 (1.2%)	320 (1.1%)	64 (2.9%)	
Asthma ED visit*	482 (1.6%)	411 (1.4%)	71 (3.2%)	<.001
Asthma hospitalization*	225 (0.8%)	227 (0.8%)	34 (1.5%)	<.001
Office visit types from January 1, 2017, to August 26, 2022				<.001
Primary care only	17,517 (56.9%)	17,305 (60.6%)	212 (9.6%)	
Pulmonary	10,917 (35.5%)	10,099 (35.3%)	818 (37.2%)	
Allergy/immunology	2,341 (7.6%)	1,170 (4.1%)	1,171 (53.2%)	

AN, Alaskan Native; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *ICS*, inhaled corticosteroid; *PI*, Pacific Islander.
*Experienced at least 1 instance in the year before the index visit.

and mold, whereas only 826 (37.5%) received tests to cockroach and 322 (14.6%) received tests to rodent. Because only 27 patients had a positive test result to rodent, a multivariable analysis for this outcome was not performed. Results of the multivariable models for positivity to each of the 8 other aeroallergen categories are shown in Fig 3 and Tables E8 and E9 (see the Online Repository at

TABLE II. Factors associated with receiving aeroallergen testing

Factor	OR (95% CI)	*P* value
Age (y) (18-34 y as reference)		
35-44	1.13 (0.95-1.34)	.18
45-54	0.86 (0.72-1.02)	.08
55-64	0.88 (0.74-1.05)	.15
≥65	0.74 (0.60-0.92)	.008
Sex (male as reference)		
Female	1.07 (0.95-1.20)	.29
Race (White as reference)		
American Indian or AN	2.43 (1.21-4.88)	.01
Asian	1.47 (1.14-1.90)	.003
Black	1.22 (1.04-1.42)	.01
Hispanic or Latino ethnicity	1.57 (1.05-2.34)	.03
Insurance status (commercial as reference)		
Medicaid	0.87 (0.74-1.02)	.09
Medicare	0.85 (0.72-1.01)	.06
ADI (1-25 as reference)		
26-50	0.84 (0.74-0.96)	.01
51-75	0.91 (0.77-1.09)	.91
76-100	0.85 (0.70-1.03)	.10
BMI (Normal as reference)		
Overweight	1.05 (0.91-1.21)	.50
Class I obesity	1.03 (0.88-1.20)	.75
Class II obesity	0.92 (0.77-1.11)	.39
Class III obesity	1.03 (0.86-1.24)	.74
Smoking category (never as reference)		
Former	1.07 (0.95-1.22)	.27
Current	0.75 (0.63-0.90)	.002
COPD	1.04 (0.90-1.20)	.63
Nasal polyposis	1.27 (1.03-1.58)	.03
Rhinitis	1.93 (1.69-2.22)	<.001
Controller inhalers prescribed (ICS only as reference)		
ICS/LABA	1.36 (1.18-1.58)	<.001
ICS/LABA and LAMA	2.66 (2.22-3.18)	<.001
OCS bursts in the year before the first office visit (0 as reference)		
1	0.94 (0.82-1.08)	.38
2-3	0.93 (0.76-1.14)	.51
≥4	1.11 (0.79-1.57)	.54
Asthma ED visit*	1.62 (1.17-2.24)	.004
Asthma hospitalization*	1.62 (1.05-2.48)	.03
Specialist visit category (primary care only as reference)		
Pulmonary	7.08 (5.91-8.48)	<.001
Allergy/immunology	91.3 (75.0-111.1)	<.001
Index visit clinic site†	0.35 (0.21-0.57)	<.001

ORs and *P* values were derived from a multivariable logistic regression model with receiving aeroallergen testing after the first clinic visit as the outcome and based on data from 30,744 patients with asthma. The *P* value for index visit clinic site was computed from a likelihood ratio test comparing the full model with a model that did not contain the index visit clinic site variable.

AN, Alaskan Native; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *ICS*, inhaled corticosteroid.

*Experienced at least 1 instance in the year before the index visit.

†Modeled as a random intercept.

www.jaci-global.org). According to these analyses, each age category older than 34 years was associated with decreased odds of positive test results for cat (OR ≤ 0.66 vs age 18-34 years [$P \leq .006$] for all comparisons), and each age category older than 44 years for tree, grass, dust mite, and dog (OR ≤ 0.64 vs age 18-34 years [$P \leq .01$] for all comparisons). Females, despite receiving tests at a rate similar to that for males (Table II and Fig 2), were less likely to have positive test results in all categories except for dog (OR ≤ 0.76 [$P \leq .02$] for all comparisons). Black patients had higher odds of positive test results in all categories than did White patients (OR ≥ 1.39 [$P \leq .03$] for all comparisons). Having an allergy/immunology visit was associated with increased odds of positive test results in 5 categories compared with having a primary care visit only (OR ≥ 1.66 [$P \leq .02$] for all comparisons). In addition, having Medicaid was associated with cockroach sensitization (OR = 2.78 vs having commercial insurance [$P = .002$]) and receiving an ICS/LABA and LAMA prescription was associated with grass sensitization (OR = 1.46 vs taking an ICS only [$P = .03$]) and cat (OR = 1.58 [$P = .008$]) sensitization.

Asthma exacerbation measures before and after aeroallergen testing

Among those patients with at least 1 positive test result (n = 1140), there were fewer OCS bursts during the 12-month period after testing than before testing: a greater number of patients had 0 bursts after testing, whereas fewer had 1, 2 or 3, or 4 or more bursts (Fig 4). Furthermore, 70.0% of patients with 4 or more bursts before had 0 to 3 bursts after testing, 65.6% with 2 or 3 bursts before had 0 or 1 bursts after testing, and 53.0% with 1 burst before had no bursts after (Table E10 in the Online Repository at www.jaci-global.org). The numbers of asthma ED visits and hospitalizations were also reduced after testing: the number of patients with 1 or more asthma ED visits was 19 after testing versus 46 before (a 58.7% reduction); the number with 1 or more asthma hospitalizations was 28 after testing versus 35 before (a 20% reduction); and 87.0% and 71.4% of patients with 1 or more asthma ED visits or hospitalizations, respectively, before testing had none after testing. Patients with any testing regardless of result (n = 1789) and patients with negative test results to all aeroallergens tested (n = 649) also had overall reductions in the number of OCS bursts, ED visits, and hospitalizations after testing versus testing before (see Figs E4 and E5 and Table E11 of the Online Repository).

DISCUSSION

This study of adults with asthma in a health system that covers a major urban area and its suburbs found that aeroallergen testing was performed at the low rate of 7.2%. This finding extends the observation by Yawn et al[39] that 1% of adults with persistent asthma in primary care had documented aeroallergen test results. In contrast to that study, our study also included data from asthma specialist clinics and therefore reflected the range of outpatient services offered to patients with asthma at a large referral center. However, 7.2% is an underestimation of the actual rate, as chart review found that 28 of 300 patients who were categorized as not tested actually had testing performed within 5 years of the index visit (9.3%), with results in their chart; this is a group that likely did not warrant repeat testing. If we extrapolate the misclassification rate of 9.3% to the full cohort, then 16% of patients either received testing within 5 years of or after the index visit (4,858 of 30,775), which is still lower than recommended by the clinical guidelines.[27]

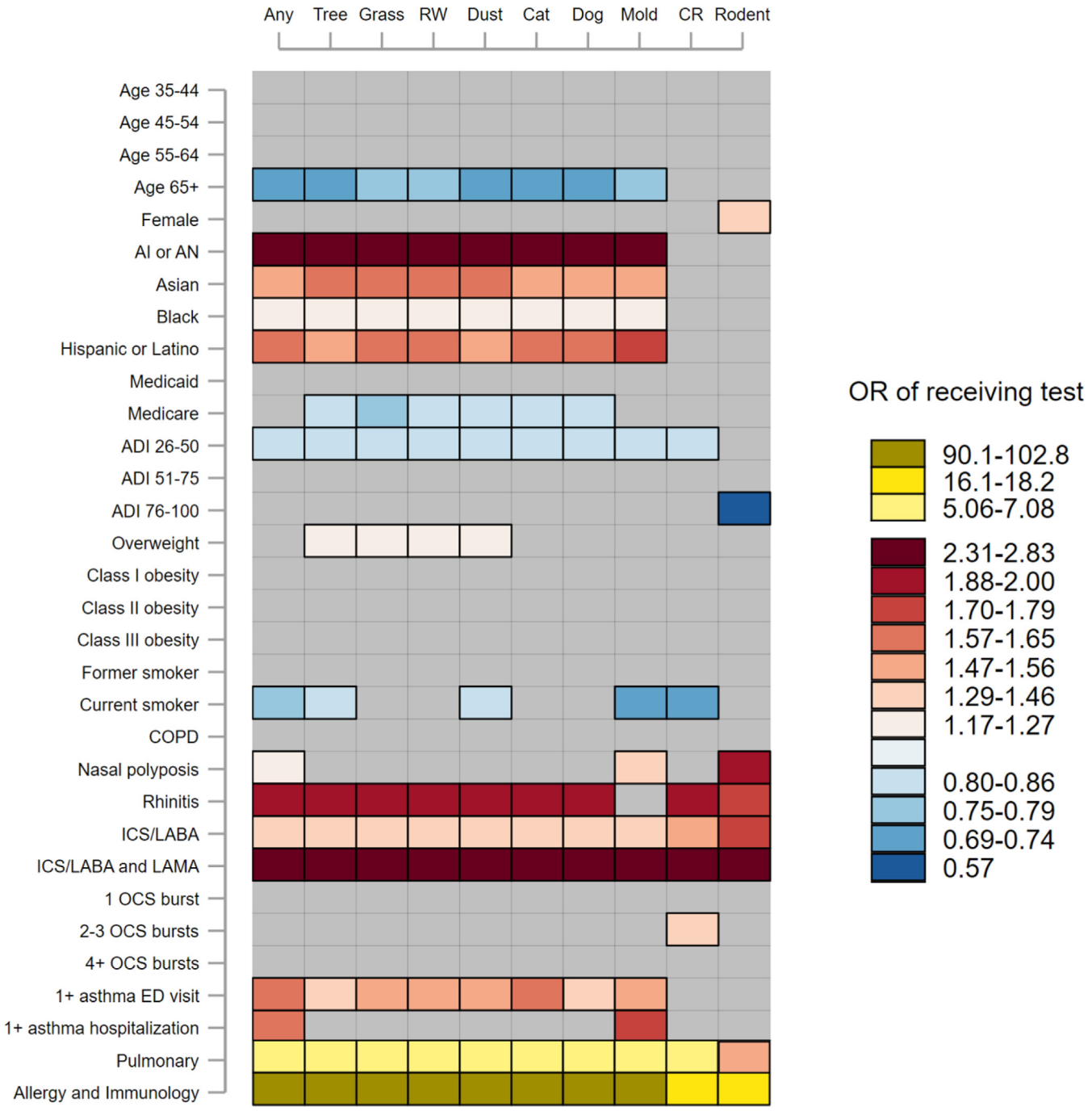

FIG 2. Heat plot of factors associated with receiving any test and for tests for each of the 9 aeroallergen categories shown on the x-axis among 30,744 patients with asthma. For each allergen category, a multivariable logistic regression model was created, with receiving a test to a category as the outcome, each variable on the y-axis included as a covariate, and the index visit clinical site modeled as a random variable (variable not shown in heat plot). Shown in each cell are the ORs of receiving tests with the first level of each variable as the reference (reference levels not shown). ORs with *P* values less than .05 in the multivariable analyses are shown as colored cells, whereas ORs with *P* values of .05 or more are shown as gray cells. *AI*, American Indian; *AN*, Alaska Native; *CR*, cockroach; *RW*, ragweed.

We found that having at least 1 allergy/immunology visit during the study period was the strongest predictor of receiving testing in the multivariable, adjusted analysis. However, it is important to note that we did not count successful referrals from primary care to asthma specialist clinics, which may represent guideline-concordant care. Regardless, our finding that 56.2% of patients in the cohort (17,305 of 30,775) had primary care visits only and were categorized as not receiving testing, despite the fact

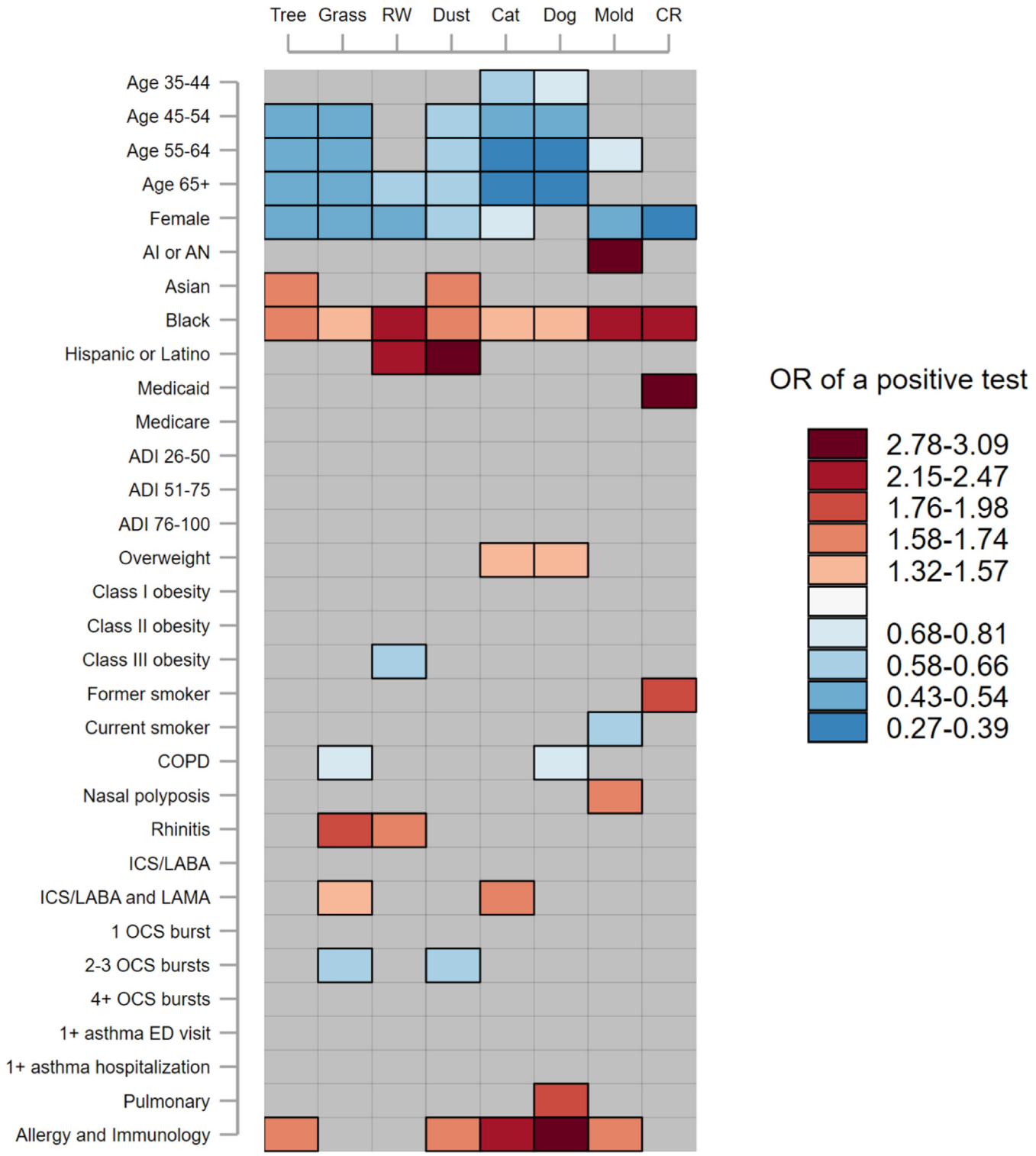

FIG 3. Heat plot of factors associated with having a positive test result in each aeroallergen category, except for rodent, among 2201 patients with asthma who received testing. The numbers of patients included in each analysis varied depending on the numbers of test results in each category (numbers shown in Fig 1 and Tables E8 and E9). For each category, a multivariable logistic regression model was created, with having a positive test result to a category as the outcome, and each variable on the y-axis included as a covariate plus a variable for test modality (variable not shown in heat plot), and the index visit clinical site modeled as a random variable (variable not shown in heat plot). Shown in each cell are the ORs of receiving tests, with the first level of each variable as the reference (reference levels not shown). ORs with *P* values less than .05 in the multivariable analyses are shown as colored cells, whereas ORs with *P* values of .05 or higher are shown as gray cells. *AI*, American Indian; *AN*, Alaska Native; *CR*, cockroach; *RW*, ragweed.

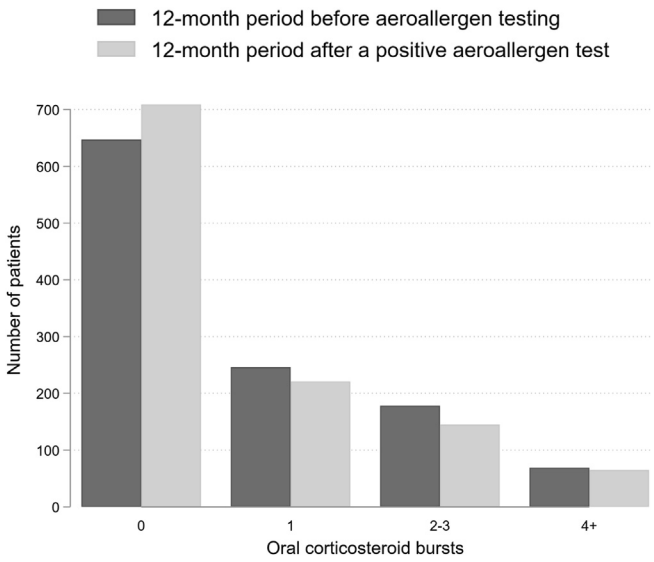

FIG 4. Side-by-side histograms of OCS bursts in the 12-month periods before and after a positive allergy test result among 1140 patients with asthma.

that any Penn Medicine provider can order serum aeroallergen testing without consulting an asthma specialist, illustrates the low rate of testing or referrals for testing in our primary care practices. The reasons for this low rate may include lack of availability of skin prick testing in primary care practices, time constraints,[41] lack of knowledge of the US asthma guidelines,[39] and inexperience with interpreting allergy test results among primary care providers. Age was another important factor, with older age associated with lower odds of receiving testing. The COVID-19 pandemic may have also contributed to the low rate, as test rates declined after the March 17, 2020, lockdown date in Philadelphia. Consistent with our expectations based on clinical indication, in the adjusted analysis for the outcome of receiving testing, patients with more severe and/or uncontrolled asthma, including those with prescriptions for multiple controller medications or asthma ED visits in the prior year, were more likely to receive testing. We also found that most aeroallergen tests were ordered as panels. Therefore, patient demographic factors associated with the outcome of receiving any test had ORs similar to those in the analyses for individual tests.

Our findings of decreased allergic sensitization with older age and in females, and increased sensitization in Black patients versus in White patients are consistent with the results of several population-based studies of adults.[42-45] It is important to note that 49% of adults aged 65 years or older who were tested for aeroallergens had at least 1 positive test result, and because older adults with asthma have been found to have higher asthma morbidity,[46] our data support the need for increased testing in this population. Some of our sensitization results suggest that EHR data could be leveraged to better understand patients' allergen exposures. For example, Medicaid insurance was highly associated with cockroach sensitization. Because cockroach allergen levels have been shown to be associated with sensitization,[38] our findings suggest that Medicaid insurance is a specific marker for cockroach exposure. More research is needed to understand trends in sensitization.

We found reductions in OCS bursts, asthma ED visits, and asthma hospitalizations after allergy testing compared with before. Possible reasons for the decrease in exacerbation measures after positive tests are improved asthma self-management or reduction of allergen exposure. The real-world benefits of allergy testing in adults with asthma are not well understood, although allergy testing as a component of self-management education has been found to improve inhaler adherence and asthma control[47] and reduce exacerbations.[48] Importantly however, because patients with negative allergy testing results also had reductions in all 3 exacerbation measures, our results may reflect the general benefits of subspecialty asthma care[49] or regression to the mean after the index visit, and thus, our study does not provide evidence that testing-based interventions caused the reductions.

Some additional limitations of our study are worth noting. Aeroallergen sensitization is not equivalent to clinical allergy, and false-positive test results are unlikely to offer benefit. However, in several studies of adults with asthma, allergic sensitization was shown to have good diagnostic accuracy in predicting allergen bronchoprovocation tests, confirming the clinical relevance of testing in these study populations.[12,50,51] Our findings may not be generalizable to other health systems. However, our large, real-world, diverse study cohort represents an important population of adults with asthma that has high disease morbidity and is often underrepresented in multisite studies. The laboratory results of this observational study are affected by sampling bias.[52] Thus, the patient demographic groups with decreased odds of receiving tests could have shown falsely low odds of positive test results, although we attempted to understand this bias by contrasting the characteristics of patients for whom tests were ordered versus those who had positive results. Those patients who had complete demographic data had characteristics different from those with missing data, and therefore, our findings may not fully reflect trends in the underlying population. Finally, as verified by chart review, our codified data extraction did not fully capture patients who received aeroallergen testing. Patients who received testing according to chart review had demographic characteristics different from those of patients who did not (Table E4), representing an important potential source of confounding. Specifically, if these additional data had been available for the analysis, it is likely that the increased odds of Black persons receiving testing versus White persons (Table II) may have been reduced or not been statistically significant, whereas the increased odds for those with commercial insurance, rhinitis, and allergy/immunology visits would have been even greater. Thus, future studies should extract testing information from notes in addition to codified data, and efforts should be made to more uniformly capture and record allergy information in the EHR to facilitate large multisite studies.

This study is the first to explore the epidemiology of aeroallergen test orders and results in a real-world population of adults with asthma. Testing was performed below the guideline-recommended rate even though testing results offer clinically actionable information, and patients who received testing had subsequent reductions in asthma exacerbation measures.

DISCLOSURE STATEMENT

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Clinical implications: Among adults with asthma in a large health system, aeroallergen testing was performed infrequently, associated with having an asthma specialist visit, and associated with decreased exacerbation measures.

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