Asthma Quality Measurement and Adverse Outcomes in Medicaid-Enrolled Children

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abstract

OBJECTIVES: To determine the association between the asthma medication ratio (AMR) quality measure and adverse outcomes among Medicaid-enrolled children with asthma in Arkansas, given concerns regarding the utility of the AMR in evaluating pediatric risk of asthma-related adverse events (AAEs).

METHODS: We used the Arkansas All-Payer Claims Database to identify Medicaid-enrolled children with asthma using a nonrestrictive case definition and additionally using the standard Healthcare Effectiveness Data and Information Set (HEDIS) persistent asthma definition. We assessed the AMR using the traditional dichotomous HEDIS AMR categorization and across 4 expanded AMR categories. Regression models assessed associations between AMR and AAE including hospitalization and emergency department utilization, with models conducted overall and by race and ethnicity.

RESULTS: Of the 22 788 children in the analysis, 9.0% had an AAE (6.7% asthma-related emergency department visits; 3.0% asthma-related hospitalizations). We found poor correlation between AMR and AAE, with higher rates of AAE (10.5%) among children with AMR $\geq$0.5 compared with AMR $<$0.5 (8.5%; $P < .001$), and similar patterns stratified by racial and ethnic subgroups. Expanded AMR categorization revealed notable differences in associations between AMR and AAEs, compared with traditional dichotomous categorization, with worse performance in Black children.

CONCLUSIONS: The AMR performed poorly in identifying risk of adverse outcomes among Medicaid-enrolled children with asthma. These findings underscore concerns of the utility of the AMR in population health management and reliance on restrictive HEDIS definitions. New population health frameworks incorporating broader considerations that accurately identify at-risk children are needed to improve equity in asthma management and outcomes.

WHAT'S KNOWN ON THIS SUBJECT: An asthma medication ratio (AMR) (ratio of asthma controller to total asthma medications) quality measure value $\geq$0.5 is typically associated with better outcomes, especially for children with persistent asthma. Evaluation of the AMR in a racially, ethnically, and geographically diverse population is limited.

WHAT THIS STUDY ADDS: Assessing the association between the AMR and adverse asthma outcomes using restrictive and nonrestrictive asthma case definitions among Medicaid-enrolled children indicated that the AMR may be a poor tool for guiding pediatric population health management programs across diverse settings.

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Asthma is the most common chronic condition among children in the United States, with significant differences in prevalence and outcomes by race and ethnicity, sex, insurance payer, and sociodemographic status.[1] In Arkansas, the racial and ethnic makeup of the pediatric population differs from national trends, with a majority of white children (58.3% Arkansas, 48% United States), a higher proportion of Black children (16.8% Arkansas, 12.6% United States), and a lower proportion of Hispanic children (13.3% Arkansas, 25.7% United States).[2] Black and Hispanic children have the highest rates of asthma nationally, with Black children having 2.5 times the rate (14.2%) and Hispanic children having 1.4 times the rate (8.0%) of asthma compared with white children (5.6%).[1,3] Additionally, previous studies in Arkansas revealed striking disparities in pediatric asthma prevalence among Arkansan children (19% compared with 8% nationally), with high asthma morbidity among racial and ethnic minority children.[4–6] Yet, significant knowledge gaps persist in our identification and understanding of children at higher risk for poor asthma outcomes, limiting opportunities for clinical intervention.[7–9]

Quality asthma care, guided by asthma management guidelines, focuses on multiple asthma measures, including asthma control, asthma exacerbations, and quality of life.[10] The National Committee for Quality Assurance (NCQA) Healthcare Effectiveness Data and Information Set (HEDIS) developed standardized metrics to compare quality of care delivery across providers and settings.[11] State Medicaid programs routinely report on National Committee for Quality Assurance-endorsed HEDIS quality measures. The HEDIS asthma medication ratio (AMR) is the most widely used asthma quality metric designed to measure adherence with asthma treatment, and has served as a proxy to identify degrees of asthma control and risk of poor outcomes. The AMR is the ratio of the number of units of asthma controller medications to the total number of units of asthma medications (controller and reliever) over a 12-month period, with lower values indicating poorer asthma control.[12–16] A major concern with the AMR, however, is how well the measure performs for population health management.[7,9,17] Ideally, improvement in the AMR within a population should be associated with decreased risks of asthma-related adverse events (AAEs) (eg, asthma-related emergency department [ED] visits and hospitalizations) across children of different ages, sex, and racial and ethnic minority status.

Multiple studies have found that a low AMR (<0.5) is associated with increased risk of ED visits and hospitalizations, whereas a high AMR (≥ 0.5) has been associated with better asthma outcomes.[12,18–20] We add to this important literature by evaluating the association of AMR with outcomes among Medicaid-enrolled children of different races and ethnicities and across a highly rural state.

Given the need for asthma population health management strategies that can be applied broadly and the known risks faced by children with asthma, it is important to understand the strengths and weaknesses of metrics such as the AMR for managing quality or risk-adjusting outcomes. In particular, we hypothesized that the AMR would not perform well in a nonrestrictive sample, overall or among children of different races and ethnicities, because of limitations in broadly identifying at-risk children.

METHODS

Population

The study was a retrospective analysis of data from the Arkansas All-Payer Claims Database (APCD) to identify Medicaid-enrolled children in Arkansas with asthma. The APCD is a large administrative database that includes clinical and pharmaceutical claims for ~500 000 commercially insured and 500 000 children covered by Medicaid annually.[21] Approximately half of all children in Arkansas are covered by Medicaid. On the basis of medical and pharmacy claims from 2018 and 2019, we identified children aged 5 to 18 years ($n = 633\,341$) with continuous (≥11 months per year) Medicaid enrollment ($n = 213\,475$). We identified children with a diagnosis of asthma ($n = 23\,174$) using a nonrestrictive case definition (ie, at least 1 asthma diagnosis International Classification of Diseases, 10th Revision, code J45.xx in 2018). Children with chronic obstructive pulmonary disease, cystic fibrosis, emphysema, or acute respiratory failure were excluded, resulting in a final analytic sample of 22 788 children (Fig 1).

HEDIS Population

Although the AMR is traditionally calculated in a HEDIS-defined persistent asthma population,[11] we chose to assess the AMR using a less restrictive sample of children with asthma (intermittent, persistent, and uncontrolled). Relaxing our case definition allowed for better understanding of the risks faced by a broad sample of children with asthma, not just high health care utilizers (eg, asthma ED visits, hospitalizations, frequent outpatient visits, multiple asthma medications), as required by the HEDIS criteria. Furthermore, we aimed to "unpack" the AMR (ie, separately evaluate patients with a 0 or missing AMR) to better understand relative performance and the extent to which the measure can assist in population health management strategies.

We assessed the sample of children who met the HEDIS definition for persistent asthma ($n = 7442$). To meet the definition of HEDIS-defined persistent asthma, the child must meet 1 of the following criteria in 2018 and 2019:

1. an ED visit with a primary diagnosis of asthma;
2. a hospitalization with a primary diagnosis of asthma;
3. 4 outpatient visits with any diagnosis of asthma and at least 2 prescriptions for HEDIS-specified asthma controller or reliever medications;

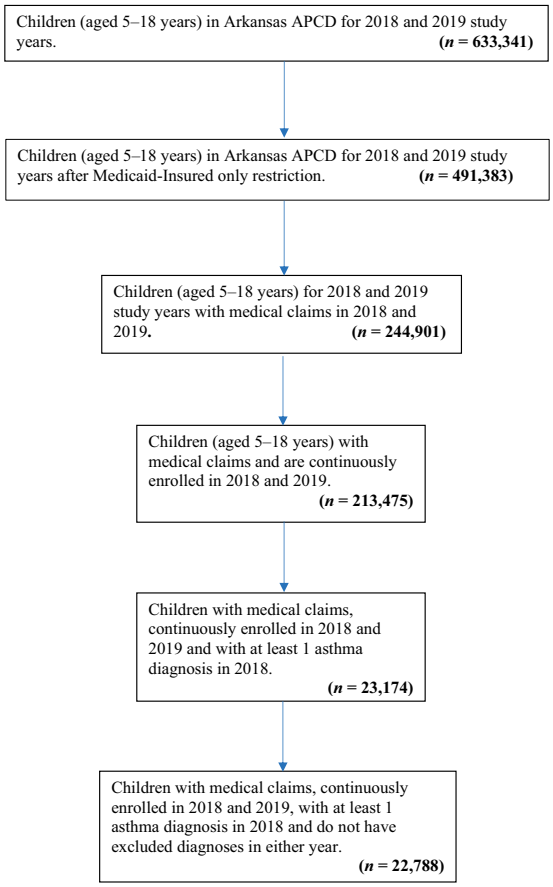

FIGURE 1
Patient inclusion and exclusions.

4. 4 prescriptions for HEDIS-specified asthma controller or reliever medications; or

5. 4 prescriptions for only leukotriene modifiers or antibody inhibitors (without other asthma medications).[11]

Primary Outcomes

The primary outcomes included asthma-related (ie, primary or secondary diagnosis of J45.xx) inpatient hospitalizations, including ICU admission, and asthma-related ED visits in 2019 that were combined into a measure of any AAE. Primary and secondary diagnoses were included to capture all ED visits and inpatient hospitalizations potentially related to an asthma exacerbation without limiting our data set. All outcomes were identified using 2019 medical claims to limit endogeneity between diagnosis and outcomes.

Asthma Medication Ratio

The AMR was the main independent variable and was calculated using 2018 pharmacy claims data. The AMR was calculated over a 12-month period and was defined as the ratio of the number of units of asthma controller medication to the total number of units of asthma medication (controller plus reliever), with each 30-day fill (inhaler canister, injection, infusion, or oral medication) being counted as 1 unit of medication.[11] Asthma controller medications are daily medications used long term to achieve and maintain asthma control.[22] Asthma reliever medications are used intermittently to manage acute asthma symptoms. The AMR ranges from 0 (reliever medications only) to 1 (controller medications only), or the AMR may be missing (no reliever or controller medications). HEDIS value set definitions using National Drug Code were used to identify all asthma medications (Supplemental Table 5).

We created distinct categories on the basis of the calculated AMR. A priori, we anticipated using the dichotomous AMR < 0.5 and AMR ≥ 0.5 on the basis of previous literature; however, upon evaluation of the data, we determined that 4 AMR categories (AMR $= 0$, $0 <$ AMR < 0.5, AMR ≥ 0.5, missing AMR) may better represent differences across patients. We additionally included AMR < 0.5 (including 0) for comparison with this commonly used category.

Covariates

We evaluated baseline patient characteristics in 2018, including demographics (age, sex, self/parent-reported race and ethnicity), clinical data, and asthma medications. Racial and ethnic categories included non-Hispanic white (white), non-Hispanic Black (Black), Hispanic or Latino (Hispanic), non-Hispanic other (other), and missing race and ethnicity (missing). The other category included reported race and ethnicity of American Indian or Alaskan Native, Asian American, Native Hawaiian or Other Pacific Islander, and other race. Clinical data were captured from medical claims, including outpatient visits, influenza vaccination status, and clinical comorbidities. Atopic status was defined as the presence of concomitant allergic conditions including allergic rhinitis, food allergy, and/or atopic dermatitis. Clinical comorbidities were determined from International Classification of Diseases, 10th Revision diagnosis codes (Table 1). Medications were identified from pharmacy claims (Supplemental Table 5).

Statistical Analysis

We used χ^2 tests to test for differences in demographic and clinical characteristics between children within each AMR classification and to assess differences in rates of AAEs among children with different demographic characteristics and AMR classifications. Linear probability regressions assessed associations between the AMR and AAEs using alternative models that allow coefficients to be compared across race and ethnicity groups. Regressions were conducted using 3 separate approaches:

1. adjusting for AMR category alone ("unadjusted"),

2. adjusting for AMR category, age, and sex ("age- and sex-adjusted"); and

3. adjusting for the full set of covariates ("fully adjusted") (Table 1).

TABLE 1 Demographic, Clinical, and Medication Characteristics Stratified by Categorical AMR

		Categorical AMR				
	All	AMR = 0	0 < AMR < 0.5	AMR ≥ 0.5	AMR Missing	
	(*n* = 22 788)	(*n* = 7174)	(*n* = 2053)	(*n* = 9799)	(*n* = 3762)	*P*
Demographic,[a] %						
Race and ethnicity						<.001
White	38.75	41.68	34.05	35.31	44.71	
Black	32.99	29.34	36.82	36.92	27.59	
Hispanic	5.98	6.27	6.23	5.89	5.50	
Other	5.10	5.41	6.09	4.45	5.69	
Missing	17.18	17.30	16.80	17.43	16.51	
Age (y)						<.001
5–11	58.57	54.34	58.84	63.70	53.16	
12–18	41.43	45.66	41.16	36.30	46.84	
Sex						<.001
Male	58.27	55.34	58.69	60.22	58.53	
Female	41.73	44.66	41.31	39.78	41.47	
Clinical,[a] %						
Outpatient visits	79.77	80.36	79.83	79.63	79.00	.384
Influenza vaccination	40.17	37.52	43.50	43.72	34.13	<.001
Atopy status	67.23	60.84	74.04	77.12	49.95	<.001
Comorbid conditions of interest						
Allergic rhinitis	53.04	45.15	59.18	64.40	35.11	<.001
Food allergy	4.53	3.12	5.50	6.33	2.02	<.001
Chronic sinusitis	3.23	2.66	2.83	3.92	2.74	<.001
Atopic dermatitis	11.69	7.88	14.42	16.14	5.87	<.001
Gastroesophageal reflux	6.69	5.41	7.60	7.86	5.61	<.001
Obesity	6.95	6.51	8.13	6.99	7.04	.083
Hypertension	1.27	1.18	1.32	1.07	1.91	.001
Vitamin D deficiency	1.33	1.35	1.12	1.20	1.70	.118
Depression	7.02	7.65	6.04	5.81	9.52	<.001
Anxiety	10.68	10.96	9.45	9.97	12.68	<.001
Autism	2.40	2.09	2.14	2.49	2.92	.041
Sleep-related breathing disorders	2.66	1.87	3.51	3.16	2.39	<.001
Medication,[a] %						
Asthma medication category						
Leukotriene modifier	2.62	0.00	5.31	4.98	0.00	<.001
ICS monotherapy	46.17	0.00	92.16	88.06	0.00	<.001
ICS/long-acting β-agonist	3.17	0.00	2.53	6.85	0.00	<.001
Other						
Oral corticosteroid	33.62	32.20	46.57	37.84	18.26	<.001

[a] All demographic, clinical, and medication characteristics are based on 2018 APCD.

Covariates and associated reference categories are profiled in Table 1. All analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC), and statistical significance was assumed at $P < .05$. This study was deemed nonhuman subjects research by the University of Arkansas for Medical Sciences institutional review board.

RESULTS

Of the 22 788 eligible children for inclusion in the study, 58.3% were male (Table 1), and the average age was 10.6 years in 2018. The racial and ethnic composition of the cohort included 38.8% white, 33.0% Black, 6.0% Hispanic, 5.1% other, and 17.2% missing race and ethnicity children. The majority of children (79.8%) were seen in an outpatient setting in 2018 and had atopy (67.2%). We found that 40.2% received an influenza vaccination in 2018. Inhaled corticosteroid (ICS) monotherapy was the predominant controller medication (46.2%). Leukotriene modifier monotherapy was used among 2.6%, and ICS plus long-acting β-$_2$-agonist was used in 3.2% of patients. In 2018, asthma biologics were used in <1% of the sample. Oral corticosteroids were used in 33.6% of patients, and the majority were short courses,

TABLE 2 Rates of Asthma Adverse Events, by Patient Demographic Characteristics and AMR Category							
	N	% With Adverse Event[a]	*P*[b]	% With ED Visit[a]	*P*[b]	% With Hospitalization[a]	*P*[b]
Full sample of patients	22 788	9.03	—	6.73	—	2.96	—
Demographic							
Race and ethnicity			<.001		<.001		.020
White	8831	8.37		5.80		3.20	
Black	7517	10.44		8.19		3.06	
Hispanic	1362	7.20		5.65		1.76	
Other	1163	8.60		7.05		2.15	
Missing	3915	8.56		6.31		2.89	
Age (y)			.102		<.001		<.001
5–11	13 348	8.77		7.35		1.97	
12–18	9440	9.40		5.86		4.36	
Average age		10.78		10.24		12.15	
Sex			.057		.623		<.001
Male	13 278	8.72		6.80		2.55	
Female	9510	9.45		6.64		3.53	
AMR							
Categorical (including 0 in <0.5 category)			<.001		<.001		.727
AMR[a] < 0.5	9227	8.46		6.09		2.98	
AMR ≥ 0.5	9799	10.53		8.34		3.02	
AMR missing	3762	6.49		4.12		2.76	
Categorical (excluding 0 in <0.5 category)			<.001		<.001		.039
AMR = 0	7174	6.75		4.45		2.72	
0 < AMR < 0.5	2053	14.47		11.84		3.90	
AMR ≥ 0.5	9799	10.53		8.34		3.02	
AMR missing	3762	6.49		4.12		2.76	

AAEs include asthma-related (ie, primary or secondary International Classification of Diseases, 10th Revision, code) hospitalization or ED visits in 2019. —, no *p* value calculated.
[a] Primary or secondary diagnosis of an asthma-related International Classification of Diseases, 10th Revision, code.
[b] *P* value associated with χ^2 test (differences in adverse event rates, by demographic characteristics or AMR category).

<7 days (prednisone: 99.3%, prednisolone: 98.7%, dexamethasone: 77.4%, methylprednisolone: 100%). In the cohort, 32.7% of children met the criteria for HEDIS-defined persistent asthma.

Primary Outcome

Overall, of the 22 788 children, 9.0% had an AAE, 6.7% had an asthma-related ED visit, and 3.0% had an asthma-related hospitalization (Table 2). Asthma-related ED visit rates were significantly higher among Black children (8.2%), compared with all other race and ethnicity groups ($P < .001$). Asthma-related hospitalization rates were higher among white children (3.2%), compared with all other race and ethnicity groups ($P = .02$).

Among children with HEDIS-defined persistent asthma, 12.9% had an AAE, 10.5% had an asthma-related ED visit, and 3.5% had an asthma-related hospitalization (Table 3). Asthma-related ED visit rates were significantly higher among Black children (13.8%), compared with all other race and ethnicity groups ($P < .001$).

AMR

Overall, 7174 children (31.5%) had an AMR = 0, 2053 (9.0%) had a 0 < AMR < 0.5, 9799 (43.0%) had an AMR ≥ 0.5, and 3762 (16.5%) had a missing AMR (Table 1). Although white children were the largest racial and ethnic group among the AMR = 0 and missing AMR categories, Black children were the largest racial and ethnic group among 0 < AMR < 0.5 and AMR ≥ 0.5 categories. Influenza vaccination and atopic comorbidity rates were highest among children with AMR ≥ 0.5 ($P < .001$).

Among the HEDIS group, 76.8% had an AMR ≥ 0.5 and 0% had a missing AMR (Table 3). Black children had the highest rates of AMR ≥ 0.5, and other race and ethnicity children had the highest rates of 0 < AMR < 0.5.

Among the full sample, AAEs were more frequent ($P < .001$) among children with 0 < AMR < 0.5 (14.5%) and AMR ≥ 0.5 (10.5%) compared with children with a 0 or missing AMR (Table 2). Additionally, asthma-related ED visit and hospitalization rates were highest ($P < .001$, $P = .04$, respectively) among children with 0 < AMR < 0.5 and AMR ≥ 0.5. When using the dichotomous AMR classification to include 0 in the AMR < 0.5 category, the rate of AAEs was lower (8.5%) than when excluding 0 (0 < AMR < 0.5 category: 14.5%).

Differences in AAEs by race and ethnicity and AMR were observed (Table 3). Hispanic children with AMR = 0 had more frequent AAEs (7.8%), compared with children of all other race and ethnicity groups with AMR = 0. Among

TABLE 3 Rates of Asthma Adverse Events by Race and Ethnicity and AMR

Full Sample	Total Sample (n = 22 788)		White (n = 8831)		Black (n = 7517)		Hispanic (n = 1362)		Other (n = 1163)		Missing (n = 3915)	
	%	P^a	%	P^a	%	P^a	%	P^a	%	P^a	%	P^a
Categorical (including 0 in <0.5 category)		<.001		.002		<.001		.009		.159		<.001
AMR < 0.5	8.46		8.70		8.81		8.82		7.80		7.38	
AMR ≥ 0.5	10.53		9.05		12.52		7.28		10.55		10.42	
AMR missing	6.49		6.24		7.71		2.42		6.54		6.44	
Categorical (excluding 0 in <0.5 category)		<.001		<.001		<.001		.005		.060		<.001
AMR = 0	6.75		7.12		6.56		7.78		6.44		5.88	
0 < AMR < 0.5	14.47		15.45		15.08		12.50		12.00		12.75	
AMR ≥ 0.5	10.53		9.05		12.52		7.28		10.55		10.42	
AMR missing	6.49		6.24		7.71		2.42		6.54		6.44	
Total % with AAE	9.03		8.37		10.44		7.20		8.60		8.56	
HEDIS sample	Total sample (n = 7442)		White (n = 2805)		Black (n = 2555)		Hispanic (n = 377)		Other (n = 357)		Missing (n = 1348)	
	%	P^a	%	P^a	%	P^a	%	P^a	%	P^a	%	P^a
Categorical (including 0 in <0.5 category)		.168		.004		.993		.791		.756		.931
AMR < 0.5	13.87		13.86		15.80		10.11		12.00		12.16	
AMR ≥ 0.5	12.61		9.96		15.82		11.11		13.23		11.98	
AMR missing	0.00		0.00		0.00		0.00		0.00		0.00	
Categorical (excluding 0 in <0.5 category)		<.001		<.001		.221		.112		.906		.162
AMR = 0	8.81		8.85		11.19		0.00		10.34		7.41	
0 < AMR < 0.5	16.90		18.48		17.47		14.75		12.68		14.89	
AMR ≥ 0.5	12.61		9.96		15.82		11.11		13.23		11.98	
AMR missing	0.00		0.00		0.00		0.00		0.00		0.00	
Total % with AAE	12.90		10.94		15.81		10.88		12.89		12.02	

AAEs include asthma-related (ie, primary or secondary International Classification of Diseases, 10th Revision, code) hospitalization or ED visits in 2019.
[a] P value associated with χ^2 test to tests for differences in AAE rates by AMR category.

children with 0 < AMR < 0.5, white (15.5%) and Black children (15.1%) had the highest rates of AAEs. Among children with AMR ≥ 0.5 and missing AMR, Black children had the highest rates of AAEs (12.5% and 7.7%, respectively).

Linear Probability Regression

In unadjusted analyses (Table 4) evaluating the association between AMR category and AAEs, 0 < AMR < 0.5 was positively correlated with asthma-related hospitalization (0.9 percentage points [pp], $P < .05$) and ED visits (3.5 pp, $P < .001$), whereas AMR = 0 and missing AMR were negatively correlated with asthma-related ED visits (−3.9 pp, $P < .001$ and −4.2 pp, $P < .001$, respectively), compared with high AMR (AMR ≥ 0.5) (Table 4). In fully adjusted analyses (Table 4) children with 0 < AMR < 0.5 had increased likelihood of asthma-related ED visits (3.0 pp, $P < .001$). In fully adjusted models, children with AMR = 0 had decreased likelihood of asthma-related ED visits (−3.3 pp, $P < .001$) and asthma-related hospitalization (−0.5 pp, $P < .05$). In fully adjusted analyses, children with missing AMR had a decreased likelihood of an asthma-related ED visit (−2.9 pp, $P < .001$) compared with children with an AMR ≥ 0.5.

When evaluating fully adjusted associations between AMR category and AAEs by race and ethnicity, having a low AMR (0 < AMR < 0.5) was associated with increased risk of asthma-related ED visits for white (5.6 pp, $P < .001$) and missing race and ethnicity (3.3 pp, $P < .05$) children, and positively associated with asthma-related hospitalization among Black children (1.7 pp, $P < .05$). Having an AMR = 0 was negatively associated with asthma-related ED visits among white (−2.0 pp, $P < .01$), Black (−5.5 pp, $P < .001$), and missing race and ethnicity children (−3.7 pp, $P < .001$), and having AMR = 0 was also negatively related to asthma-related hospitalization for missing race and ethnicity children (−1.4 pp, $P < .05$). Children with missing AMR were less likely to have asthma-related ED visits among white (−1.7 pp, $P < .05$), Black (−4.4 pp, $P < .001$), and missing race and ethnicity (−2.8 pp, $P < .05$) children, and missing AMR was negatively correlated with asthma-related hospitalization for white children (−1.5 pp, $P < .01$).

DISCUSSION

The AMR is used under the hypothesis that better asthma quality of care, represented by higher AMR, improves medication adherence, and subsequently asthma control and outcomes, especially for children with persistent asthma.[12,18–20] Accordingly, the AMR, and other HEDIS quality metrics, although not specifically designed for risk prediction, were

TABLE 4 Linear Probability Adverse Event Regressions, Overall and Stratified by Race and Ethnicity

Asthma-Related Hospitalization						
Unadjusted (model 1)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−0.30	−0.24	−0.24	0.49	0.49	−1.12
0 < AMR < 0.5	0.88*	1.21	1.91**	0.61	0.57	−1.72
AMR missing	−0.26	−0.86	0.72	−1.25	0.50	−0.40
Age and sex adjusted (model 2)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−0.57*	−0.61	−0.45	0.35	0.37	−1.38*
0 < AMR < 0.5	0.75	0.97	1.88**	0.57	0.34	−1.80
AMR missing	−0.52	−1.20*	0.44	−1.33	0.32	−0.59
Fully adjusted[a] (model 3)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−0.54*	−0.70	−0.34	0.15	0.71	−1.39*
0 < AMR < 0.5	0.73	0.85	1.68*	0.59	0.93	−1.66
AMR missing	−0.63	−1.48**	0.56	−1.35	−0.34	−0.58
Asthma-related ED visits						
Unadjusted (model 1)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−3.89***	−2.09***	−6.26***	−0.12	−3.30	−3.96***
0 < AMR < 0.5	3.50***	5.94***	1.48	4.26	1.68	3.69**
AMR missing	−4.22***	−2.25**	−6.14***	−3.96*	−4.04	−4.20***
Age and sex adjusted (model 2)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−3.79***	−2.10***	−6.05***	0.08	−3.31	−3.85***
0 < AMR < 0.5	3.55***	5.94***	1.52	4.32	1.67	3.77**
AMR missing	−4.10***	−2.26**	−5.89***	−3.87*	−4.05	−4.03***
Fully adjusted[a] (model 3)						
	All	White	Black	Hispanic	Other	Missing
AMR ≥ 0.5	Ref	Ref	Ref	Ref	Ref	Ref
AMR = 0	−3.33***	−1.95**	−5.52***	0.83	−3.24	−3.68***
0 < AMR < 0.5	3.01***	5.57***	0.60	4.36	1.22	3.32*
AMR missing	−2.93***	−1.66*	−4.44***	−2.54	−3.34	−2.83*

Racially and ethnically stratified models were run on each subpopulation independently. All column represents regression run on full sample with individual racial and ethnic categories. All regression coefficients represent pp changes. Ref, reference.

[a] Fully adjusted model includes demographic, clinical, and medication covariates in addition to AMR. Racial and ethnic categories used as covariates in fully adjusted models.

* $P < .05$; ** $P < .01$; *** $P < .001$.

developed to allow performance comparison across providers, facilities, and health plans to inform population health management.[9,17] In our sample of Medicaid-enrolled children with asthma identified with a nonrestrictive case definition, however, we found limited evidence that the AMR can guide population health management strategies to identify at-risk children, highlighting the inadequacies in the focus of the AMR.[9,17,23] Although the AMR is designed for use in HEDIS-defined persistent asthma populations, use of a more restrictive population does not allow for assessment of children with less utilization, but are still at risk for poor outcomes. Although only one-third of our cohort met HEDIS criteria, using our relaxed criteria, children identified were found to be at significant risk of AAEs, underscoring the concern that utilizing restrictive HEDIS asthma case identification may inadvertently exclude at-risk children.[7,17] These findings suggest the need for new population health frameworks to reliably identify at-risk children, which is critical for equitable allocation of resources to prevent AAEs.

Racial and ethnic differences in AAEs were also observed. Notably, in our cohort, there was large variation between ED visits and hospitalizations among Black children compared with white children. For white children, the difference between ED visits and hospitalizations was 2.6 pp, whereas for Black children, the difference was 5.1 pp. One study of pediatric ED care found that, relative to white children, Black children were 28% less likely to be admitted to the hospital after an ED visit.[24] These findings were partially explained by differences in ED triage, with Black children more likely to be triaged as semi- or nonurgent, consistent with other literature,[25] and differences in ED utilization for nonurgent care needs (higher ED utilization for nonurgent care).[26] In our study, white children had higher rates of asthma-related hospitalizations, compared with Black children. Our findings may be explained, at least in part, by the effects of racism (interpersonal and institutional),[27,28] underpinning differences in health care access,[29] ED triage,[25] ED wait times,[30] and management[24,31,32] that may impact disposition.[33] Black children had higher rates of asthma-related ED visits, consistent with previous studies.[34] Although Hispanic children have high rates of asthma morbidity nationally,[1] we did not observe this in our cohort. This is likely because of several considerations. First, in Arkansas, there is not a large Hispanic population[35] (only 6% of our cohort was Hispanic), limiting evaluations of outcomes in this group. Second, Puerto Rican children have worse asthma outcomes among Hispanic populations overall,[1] and in Arkansas, there is not a significant Puerto Rican population. Third, our analysis is limited to Medicaid-enrolled children, and there is a disproportionate percentage of the Hispanic population in the state who are employed by large, self-insured employers or who are employed in the farming industry where they are less likely to be enrolled in any health plan.

We found that children with HEDIS-defined persistent asthma had a higher risk of AAEs mainly because of increased risk of an ED visit, with hospitalization rates being similar across samples. Though the AMR did perform as expected in the HEDIS-defined persistent asthma sample, with an AMR ≥ 0.5 being associated with lower rates of AAEs, minimal differences in rates of AAEs between the AMR ≥ 0.5 and AMR < 0.5 groups (13.9% vs 12.6%) were found. When 0 was excluded from the low AMR category (0 < AMR < 0.5), the rates of AAEs increase to

16.9%, indicating that evaluation of 0 AMR separately, even in the HEDIS population, is important. Additionally, given that most of the children with persistent asthma had an AMR $\geq$ 0.5 (76.8%), focusing on increasing the AMR may have limited ability to reduce AAEs in a sample of children with HEDIS-defined persistent asthma.

In contrast, the AMR performed less reliably in children identified using a nonrestrictive asthma definition, and when the AMR was expanded into 4 distinct categories (AMR = 0, 0 < AMR < 0.5, AMR $\geq$ 0.5, and missing AMR). Only 43% of children in the larger sample had an AMR $\geq$ 0.5, and children with a low AMR had a rate of AAEs $\sim$4.0 pp higher compared with children with high AMR. Although almost one-third of children had an AMR = 0 (relievers asthma medication only), presumably corresponding to patients with intermittent asthma symptoms that are managed with reliever medications and do not require controller asthma medications, we found that 6.8% of this population had an AAE. This suggests that a portion of these children with AMR = 0 may actually have poorly controlled or undiagnosed persistent asthma, rather than intermittent asthma. Of note, the rate of AAEs among the AMR = 0 group in the nonrestrictive group was only 2.1 pp lower than rate of AAE among the AMR = 0 group in the HEDIS population, which should only include children with persistent asthma, but likely represents children who are undertreated or who have poor medication adherence. Although previous studies of children with missing AMR (no controller or reliever asthma medication) suggested that these children are likely to have inactive asthma,[16,36] we found that 6.5% of children with missing AMR had an AAE, suggesting that these children potentially have undiagnosed persistent asthma, rather than intermittent asthma. Overall, considering 0 and missing values separately may be required as a first step toward a modified AMR with utility in risk prediction.

Our findings underscore the importance of including all children across the asthma severity spectrum to accurately assess the true risk of adverse outcomes across populations. This calls into question the value of the AMR and the narrow HEDIS definition in asthma population health management programs when considering a broad sample of children that may experience hospitalization or emergency care use related to their asthma.

A final test of the AMR concerned whether associations between the AMR categories and AAEs were similar across children by race and ethnicity. One previous study has evaluated AMR and the Medication Management for Asthma (MMA) [retired in 2017] by race and ethnicity and found discordance between AMR and MMA, with Black children 14 pp more likely to have a high AMR and a low MMA, and no association between AMR or MMA and AAEs.

Overall, we found that Black children were more likely to have a high AMR and had higher rates of AAEs, but differences in risk of AAEs between high and low AMR categories for Black children were minimal, whereas the difference in risks of AAEs was large for white children. Further, in regression models, although Black children had higher rates of asthma-related ED visits, Black children with low AMR did not have significant difference in risk of asthma-related ED visit compared with those with high AMR. In contrast, white children with low AMR had significantly higher risk of asthma-related ED visits compared with those with high AMR (5.6 pp, $P < .001$) in fully adjusted models. This supports evidence of additional factors differentially impacting Black children at risk for AAEs that are not captured by the AMR, including structural racism, socioeconomic and environmental variables, and social determinants of health.[37–42] Given the significant racial disparities in asthma morbidity and mortality among Black and Hispanic children, it is particularly important to improve ways to identify and target children at high risk for poor asthma outcomes in these communities.

Of note, our study analysis is over a 2-year period, 2018 and 2019, before publication of the updated 2020 Expert Panel Report 4 asthma management guidelines.[10] The update highlights a major change in asthma medication management with the use of ICS/formoterol as both a controller and a reliever. This change, although less relevant to this study, will impact future evaluations of the AMR that will need to be considered, and will likely further decrease the utility of the metric.

The study has several limitations. First, our analysis included a Medicaid-enrolled population from 1 state, limiting generalizability. Also, it is possible that our findings on the AMR and AAEs are related to having a high percentage of children with persistent asthma using controller medications. Importantly, our study is 1 of a few that is specifically focused on an understudied diverse population in Arkansas, a highly rural state, and we benefit from using statewide data. Focused investigation of regions with significant rural populations, and with high proportions of racial and ethnic minority populations, in contrast to predominantly white rural areas, is essential in understanding differences in quality of care and outcomes.[43–46] Second, we used administrative claims data, which are limited in capturing comprehensive clinical data relevant to asthma care and patient risk, as well as demographic data such as race and ethnicity. The APCD contains self/parent-reported race and ethnicity data, but 17.2% of our population had missing data. In a sensitivity analysis (data not shown), we assigned race and ethnicity information for individuals with missing data using majority race and ethnicity (75% or more) within zip codes, which reduced missing values by 31% (from 17.2% to 11.8%), with no change in reported outcomes. Third, we measured the AMR in 2018 and AAEs in 2019, in accordance with other studies,[12–19] because we aimed

to measure whether the AMR could be predictive of future adverse events. It is possible that, if the AMR and AAEs were measured in the same year, the AAE could lead to increased asthma controller prescriptions and claims, and to improved AMR. Finally, we used a nonrestrictive asthma case definition, which may limit comparisons with previous studies. Notably, our case definition (Medicaid-enrolled, 2-years continuous enrollment, medical claims for 2 years, 1 asthma diagnosis), although less restrictive than HEDIS, did limit our sample several fold. The most significant "restriction," however, was at least 1 asthma diagnosis in 2018. Because asthma diagnosis is a necessary restriction, we aimed for our subject selection to capture a population of patients with asthma in which we could evaluate race and ethnicity. We chose to focus on Medicaid because of the availability of race and ethnicity data for Medicaid-enrolled compared with commercially insured patients. Further, we aligned our methods with previous studies and AMR calculation methodology,[11] which requires 2 years of continuous enrollment and minimal gaps in coverage, and we required medical claims for 2 years to decrease missing data, specifically for calculation of baseline characteristics and adverse outcomes. We found this method of subject selection to be important in capturing all children who are potentially at risk for adverse asthma outcomes, inclusive of those with persistent asthma and those who may have intermittent, uncontrolled, or undertreated asthma.

CONCLUSIONS

Exploring relationships between asthma quality metrics and AAEs is important in identifying at-risk children in need of clinical intervention. Although previous studies have found low AMR to be associated with poor asthma outcomes, in our analysis, the AMR performed poorly in describing the risk of adverse outcomes among a diverse, Medicaid-enrolled population of children with asthma in Arkansas. The study findings support the need for new population health management strategies for identifying at-risk children that incorporate measures other than the AMR. In particular, the findings call into question population-based frameworks using the AMR and reliance on HEDIS-defined populations, because resource allocation based on this framework may contribute to persistent asthma disparities and health inequities. A new framework that identifies and integrates additional clinical characteristics, demographic data such as race and ethnicity, geographic information, and social determinants of health to build appropriate risk prediction models is needed to improve equity in asthma outcomes.

ABBREVIATIONS

AAE: asthma-related adverse event
AMR: asthma medication ratio
APCD: Arkansas All-Payer Claims Database
ED: emergency department
HEDIS: Healthcare Effectiveness Data and Information Set
ICS: inhaled corticosteroid
MMA: Medication Management for Asthma
pp: percentage points

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