Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Original Article

Pediatric Asthma Health Care Utilization, Viral Testing, and Air Pollution Changes During the COVID-19 Pandemic

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What is already known about this topic? The coronavirus disease 2019 pandemic caused dramatic changes to daily routines and health care delivery in the United States.

What does this article add to our knowledge? Coronavirus disease 2019 public health interventions were accompanied by a reduction in pediatric asthma encounters and systemic steroid prescriptions. Decreased rhinovirus infections may have contributed to this apparent reduction in asthma exacerbations, although changes in 4 criteria air pollutants were not significantly different than historical trends.

How does this study impact current management guidelines? Our findings reinforce the value of preventative measures for asthma control, especially those designed to limit transmission of respiratory viruses.

BACKGROUND: The coronavirus disease 2019 (COVID-19) pandemic caused dramatic changes in daily routines and health care utilization and delivery patterns in the United States. Understanding the influence of these changes and associated public health interventions on asthma care is important to determine effects on patient outcomes and identify measures that will ensure optimal future health care delivery.

OBJECTIVE: We sought to identify changes in pediatric asthma-related health care utilization, respiratory viral testing, and air pollution during the COVID-19 pandemic.

METHODS: For the time period January 17 to May 17, 2015 to 2020, asthma-related encounters and weekly summaries of respiratory viral testing data were extracted from Children's Hospital of Philadelphia electronic health records, and pollution data for 4 criteria air pollutants were extracted from AirNow. Changes in encounter characteristics, viral testing patterns, and air pollution before and after Mar 17, 2020, the date public health interventions to limit viral transmission were enacted in Philadelphia, were assessed and compared with data from 2015 to 2019 as a historical reference.

RESULTS: After March 17, 2020, in-person asthma encounters decreased by 87% (outpatient) and 84% (emergency + inpatient). Video telemedicine, which was not previously available, became the most highly used asthma encounter modality (61% of all visits), and telephone encounters increased by 19%. Concurrently, asthma-related systemic steroid prescriptions and frequency of rhinovirus test positivity decreased, although air

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Abbreviations used
CHOP- Children's Hospital of Philadelphia
COVID-19- Coronavirus disease 2019
ED- Emergency department
EPA- Environmental Protection Agency
IFV-A- Influenza virus A
IFV-B- Influenza virus B
$PM_{2.5}$- Particulate matter less than 2.5 microns
PM_{10}- Particulate matter less than 10 microns
RSV- Respiratory syncytial virus
RV- Rhinovirus
SARS-CoV-2- Severe acute respiratory syndrome coronavirus 2
VTM- Video telemedicine

pollution levels did not substantially change, compared with historical trends.
CONCLUSIONS: The COVID-19 pandemic in Philadelphia was accompanied by changes in pediatric asthma health care delivery patterns, including reduced admissions and systemic steroid prescriptions. Reduced rhinovirus infections may have contributed to these patterns. **(J Allergy Clin Immunol Pract 2020;8:3378-87)**

Key words: *Asthma; COVID-19; Pollution; Telemedicine; Respiratory virus*

INTRODUCTION

Coronavirus disease 2019 (COVID-19), an illness caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), arose in late 2019 and rapidly spread around the world. By June 2020, more than 9 million cases and 469,000 deaths had been reported worldwide, with 2.3 million cases and 122,000 deaths in the United States.[1] In response to COVID-19,[2] health care systems reoriented their delivery structures to prepare for a dramatic increase in COVID-19 cases while attempting to shield unaffected individuals from infection. Simultaneously, various local and national public health interventions designed to limit viral transmission were enacted. At Children's Hospital of Philadelphia (CHOP), the first COVID-19 patient tested positive for SARS-CoV-2 on March 17, 2020. On this date, all nonessential businesses in Philadelphia were prohibited from operating in person.[3] Subsequently, the city enacted a stay-at-home order and a closure of schools, with the intent to limit physical interactions among people and prevent transmission of the virus. Concern arose among patients and their parents that visiting a hospital or doctor's office put them at increased risk for contracting COVID-19, resulting in deferral of many in-person well-child and routine follow-up care visits.[4,5] For all these reasons, many health care systems, including CHOP, adopted video telemedicine (VTM).[6]

Asthma is one of the most common chronic childhood diseases, affecting 1 of 12 school-age children in the United States,[7] with a higher prevalence in Philadelphia than the national mean.[8,9] Pollution and respiratory virus exposure, in particular rhinovirus (RV),[10,11] can worsen asthma symptoms and trigger exacerbations.[12] For example, exposure to US Environmental Protection Agency (EPA) criteria air pollutants, including particulate matter less than 2.5 microns ($PM_{2.5}$), particulate matter less than 10 microns (PM_{10}), ozone, and nitrogen dioxide (NO_2), has been associated with increased asthma exacerbations[13-16] and increased risk of developing asthma.[17] Viral respiratory infections are also associated with most pediatric asthma exacerbations,[18] and people with asthma experience more severe, longer-lasting respiratory viral infections than people without asthma.[19] Based on these findings, it was thought that people with asthma were at risk for worse COVID-19 outcomes,[20,21] although subsequent observational studies have found mixed results in support of this hypothesis.[22-24]

The public health interventions adopted to slow down the transmission of SARS-CoV-2 have altered environmental exposure profiles, which also influence the risk of asthma exacerbations. Infection prevention measures, including wearing face masks, washing hands frequently, and social distancing as a result of stay-at-home orders and school closures, reduce person-to-person transmission of all respiratory viruses. The decrease in transportation and industrial activity resulting from COVID-19 restrictions has reduced the emission of primary air pollutants worldwide,[25,26] and there is current interest in determining the extent to which these changes have affected asthma symptoms.[27] In this study, we sought to describe the impact of COVID-19 public health measures on pediatric asthma-related health care utilization, respiratory virus testing in our emergency department (ED), and pollution levels in the greater Philadelphia area.

METHODS

Study population

We extracted asthma patient encounter data corresponding to the time period January 17 to May 17 for the years 2015 to 2020 from the CHOP Care Network, which consists of 48 outpatient primary and specialty care clinical sites, 4 urgent care sites, 15 community hospital alliances, and a 557-bed quaternary care center in the greater Philadelphia area. Data from this network have previously been validated as a tool to assess regional disease trends.[8,28] Asthma diagnosis was established on the basis of encounters having an *International Classification of Diseases, Tenth Revision* code J45.nn. Accuracy of this definition was confirmed via manual review of 100 patient charts.

Variable selection

For each encounter, its type (ie, inpatient, ED, outpatient, telephone, and VTM) and date were extracted, along with data on the patient's sex, race, ethnicity, date of birth, and payer type. Race was based on self- or parent/guardian selection of 1 of the following categories: "white," "black," "Asian or Pacific Islander," or "Other." Subjects without a race selection were coded as "Unknown." Codified asthma-related drug prescription data for all outpatient asthma-related prescriptions, and for outpatient and inpatient systemic steroid prescriptions, were obtained from CHOP provider prescription records (see Table E1 in this article's Online Repository at www.jaci-inpractice.org).

Virology data

CHOP ED results for respiratory viral testing for adenovirus, influenza A virus (IFV-A), influenza B virus (IFV-B), parainfluenza 1, parainfluenza 2, parainfluenza 3, non−COVID-19 coronavirus, metapneumovirus, respiratory syncytial virus (RSV), RV, and COVID-19 via PCR testing were extracted from CHOP's Respiratory Virus Prevalence database. Data for the number of positive test results and tests administered for each virus for the time period

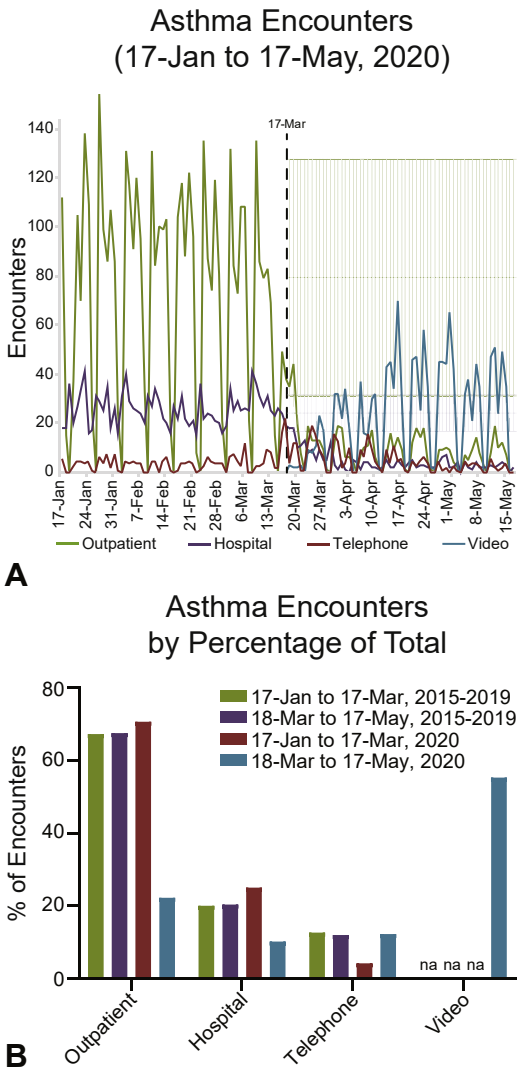

FIGURE 1. Asthma encounters before and after public health interventions were enacted. (**A**) Daily asthma encounters from January 17 to May 17, 2020. Outpatient (primary + specialty care), telephone calls (telephone), hospital (ED + inpatient), and video (primary + specialty care) encounters are shown. Five-year historical averages (March 18 to May 17, 2015-2019) with 1 SD from the mean for outpatient (light green) or hospital (light purple) encounters shown. March 17 (black-dotted line) is the date Philadelphia prohibited the operation of nonessential businesses (effective 5 PM), and the date the first COVID-19 case was diagnosed at CHOP. (**B**) Historical and 2020 asthma encounters as a percentage of total. NA, Not applicable/available.

January 17 to May 17 during the years 2015 to 2020 were obtained. The number of positive test results for each virus was compared with (1) the total number of tests administered for that virus only and (2) the overall number of viral tests administered for all the viruses listed above.

Air pollution data

Hourly $PM_{2.5}$, PM_{10}, ozone, and NO_2 measures obtained at EPA monitoring sites in Philadelphia for the time period January 17 to May 17 during the years 2015 to 2020 were extracted from AirNow, an air quality data management system that reports real-time and forecast air quality estimates.[29] Because historical data were not available for all pollutants in AirNow, we also downloaded daily summary files for the time period January 17 to May 17 during the years 2015 to 2019 from Air Data, an EPA resource that provides quality-assured summary air pollution measures collected from outdoor regulatory monitors across the United States.[30] In Philadelphia, the same monitoring sites transmitted data to AirNow and AirData.

Data analysis

Characteristics of encounters, viral test results, and pollutant levels from the 60-day period before and after March 17, 2020 were compared with those from the period 2015 to 2019. A paired Student *t* test was used to examine differences in systemic steroid prescription rates between patients before and after March 17. For both viral testing and pollution data, controlled interrupted time series regression models were created to identify statistically significant changes between the pre—and post—March 17 60-day time frames that differed in 2020 compared with the 2015 to 2019 historical time period. Significant differences between 2020 and historical data were determined on the basis of *P* values for regression coefficients corresponding to interaction terms of variables representing pre—and post—March 17 status, the year(s) in question, and/or days. For viral testing, 2-way ANOVA and mixed-effect analysis were additionally used to test for significant differences. To visualize pollution levels across Philadelphia during time periods of interest, we generated 100 m × 100 m grid raster layers using inverse-distance-squared weighted averaging of pollutant measures from the 5 nearest monitoring stations. Analyses were performed in GraphPad Prism (GraphPad Software, San Diego, Calif) and R (R Foundation, Vienna, Austria).[31] Results were summarized as percentage change.

Data availability

The epidemiologic data sets supporting the conclusions of this article are available in the Zenodo repository (https://zenodo.org/record/3981568).

Ethical and regulatory oversight

The CHOP Institutional Review Board reviewed our study and determined it did not meet the definition of Human Subjects research.

RESULTS

Asthma health care utilization decreased and VTM encounters increased after COVID-19 public health interventions

Before the public health measures enacted on March 17, 2020 in Philadelphia to limit COVID-19 spread, asthma health care visit numbers and encounter types at CHOP were similar to historical averages for the period 2015 to 2019. Overall, there was a 60% decrease in total daily asthma health care visits at CHOP when comparing the 60 days before and after March 17, 2020 (102.44 ± 48.9; range, 19-190, and 41.5 ± 25.7, range, 0-94, respectively) (Figure 1). Before March 17, 2020, the average numbers of outpatient and hospital (ED + inpatient) daily asthma encounters were 72.5 ± 46.2 (range, 0-154) and 25.7 ± 6.6 (range, 0-41), respectively. After March 17, 2020, the average number of daily outpatient encounters decreased by 87%

TABLE I. Demographic characteristics of subjects with asthma by time period and encounter type

	Cohort (n)										
	2015-2019	January 17-March 17, 2020 (5,190)					March 18-May 17, 2020 (2,273)				
Characteristic	All (23,146)	Outpatient	Hospital	Telephone	Video	All	Outpatient	Hospital	Telephone	Video	All
Sex, n (%)											
Male	13,644 (59)	2,275 (59)	826 (58)	155 (62)	0 (0)	3,035 (58)	253 (56)	122 (50)	169 (57)	808 (59)	1,294 (57)
Female	9,502 (41)	1,608 (41)	603 (42)	97 (38)	0 (0)	2,155 (42)	196 (44)	124 (50)	129 (43)	573 (41)	979 (43)
Race, n (%)											
White	9,536 (41)	1,711 (44)	251 (18)	151 (60)	0 (0)	2,007 (39)	131 (29)	31 (13)	103 (35)	747 (54)	979 (43)
Black	9,678 (42)	1,366 (35)	927 (65)	60 (24)	0 (0)	2,139 (41)	242 (54)	191 (78)	145 (49)	356 (26)	880 (39)
Asian/Pacific Islander	731 (3)	168 (4)	45 (3)	6 (2)	0 (0)	204 (4)	10 (2)	3 (1)	8 (3)	37 (3)	57 (3)
Other	3,109 (13)	606 (16)	203 (14)	34 (13)	0 (0)	805 (16)	64 (14)	21 (9)	42 (14)	234 (17)	348 (15)
Unknown	92 (0)	32 (1)	3 (0)	1 (0)	0 (0)	35 (1)	2 (0)	0 (0)	0 (0)	7 (1)	9 (0)
Ethnicity, n (%)											
Non-Hispanic/Latino	20,997 (91)	3,426 (88)	1,274 (89)	223 (88)	0 (0)	4,579 (88)	398 (89)	228 (93)	268 (90)	1,217 (88)	2,018 (89)
Hispanic/Latino	1,974 (9)	419 (11)	152 (11)	27 (11)	0 (0)	568 (11)	50 (11)	18 (7)	27 (9)	149 (11)	237 (10)
Unknown	175 (1)	38 (1)	3 (0)	2 (1)	0 (0)	43 (1)	1 (0)	0 (0)	3 (1)	15 (1)	18 (1)
Birth year, n (%)											
Before 2000	1,333 (6)	22 (1)	1 (0)	3 (1)	0 (0)	26 (1)	9 (2)	0 (0)	4 (1)	8 (1)	20 (1)
2000-2004	4,096 (18)	414 (11)	124 (9)	45 (18)	0 (0)	554 (11)	68 (15)	35 (14)	64 (21)	144 (10)	295 (13)
2005-2009	6,973 (30)	979 (25)	268 (19)	57 (23)	0 (0)	1,231 (24)	130 (29)	52 (21)	62 (21)	312 (23)	532 (23)
2010-2014	8,057 (35)	1,343 (35)	492 (34)	89 (35)	0 (0)	1,784 (34)	141 (31)	82 (33)	91 (31)	473 (34)	753 (33)
2015 or later	2,687 (12)	1,125 (29)	544 (38)	58 (23)	0 (0)	1,595 (31)	101 (22)	77 (31)	77 (26)	444 (32)	673 (30)
Payer type, n (%)											
Non-Medicaid	13,676 (59)	2,283 (59)	532 (37)	222 (88)	0 (0)	2,863 (55)	201 (45)	66 (27)	254 (85)	969 (70)	1,446 (64)
Medicaid	9,470 (41)	1,600 (41)	897 (63)	30 (12)	0 (0)	2,327 (45)	248 (55)	180 (73)	44 (15)	412 (30)	827 (36)

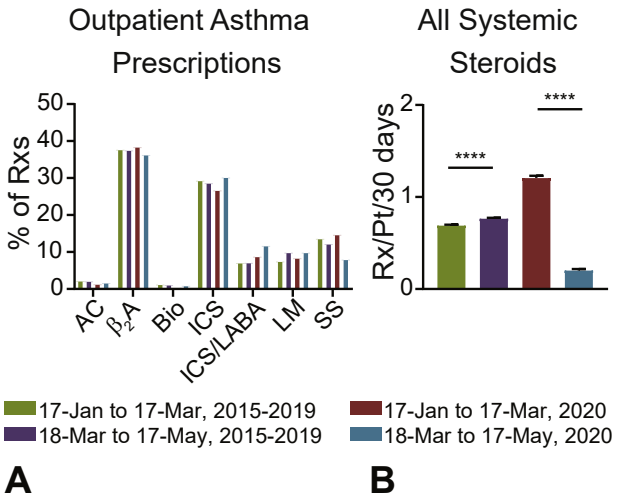

FIGURE 2. Asthma prescriptions before and after public health interventions were enacted. (**A**) Outpatient asthma-related prescriptions by medication class as a percentage of total (*AC*, anticholinergic; *β_2A*, β_2 agonists; *Bio*, biologic; *ICS*, inhaled corticosteroid; *ICS + LABA*, ICS with long-acting beta-agonist; *LM*, leukotriene modifier; *Rxs*, prescriptions; *SS*, systemic steroid). (**B**) Average number of systemic steroid prescriptions per patient per 30 days from any primary asthma encounter (outpatient, emergency, inpatient). Mean + SEM shown. Statistical comparison by paired Student *t* test. ****$P < .0001$.

to 9.2 ± 8.2 (range, 0-44), while hospital encounters decreased by 84% to 4.2 ± 3.8 (range, 0-18). Concurrently, asthma telephone encounters across the network increased by 19% from a daily average of 4.3 ± 4.2 (range, 0-24) to 5.1 ± 5.3 (range, 0-21) after March 17, 2020. VTM was not available before March 17, 2020, but was quickly adopted: asthma VTM encounters averaged 23.0 ± 19.9 per day (range, 0-70) and accounted for 61% of all encounters after March 17, 2020.

Demographic differences in asthma health care utilization and adoption of VTM

Per-patient demographic characteristics of our study population are presented in Table I. Although the total number of asthma encounters decreased after March 17, 2020, black patients represented a higher proportion of outpatient, hospital, or telephone care after this date compared with the preceding 60-day time period (54% vs 35%, 78% vs 65%, and 49% vs 24%, respectively). Patients with Medicaid coverage represented a higher proportion of outpatient or hospital care after March 17 compared with the pre—March 17, 2020 time period (55% vs 41% and 73% vs 63%, respectively). Of patients who engaged in VTM encounters in the post—March 17, 2020, time period, 26% were black and 30% had Medicaid coverage.

Decreased prescriptions of systemic steroids after COVID-19 public health interventions

Comparison of pre—and post—March 17, 2020 CHOP prescription patterns found that the relative proportions of most outpatient asthma-related prescriptions were similar before and after introduction of COVID-19 public health interventions (Figure 2, *A*). One exception was outpatient systemic steroid prescriptions, which were proportionally reduced compared with other asthma-related medications after the introduction of COVID-19 public health interventions (Figure 2, *A*). When limiting the comparison to patients who had at least 1 systemic steroid prescription from any primary asthma encounter (outpatient, emergency, or inpatient) between January 17 and May 17, 2020, there was a 83% decrease in systemic steroid prescriptions (Figure 2, *B*). Black patients and patients with Medicaid coverage represented the highest proportion of steroid prescription encounters between March 17 and May 17, 2020 (70% and 63%, respectively) (see Table E2 in this article's Online Repository at www.jaci-inpractice.org).

Decreased RV infections after COVID-19 public health interventions

Given the importance of respiratory viral infections in asthma exacerbations, we sought to quantify the impact of COVID-19 public health interventions on respiratory viral testing. We focused on 4 key viruses; IFV-A, IFV-B, RSV, and RV. When examining viral data for the period 2019 to 2020, we noted variations in season onset and peak timing compared with historical trends. The IFV-A viral season had variable timing year-to-year and had neither an early nor a late season in the period 2019 to 2020 (Figure 3, *A*). The IFV-B viral season had an earlier onset and peaked earlier in the period 2019 to 2020, as compared with recent previous years (Figure 3, *B*). Both the IFV-A and IFV-B seasons were waning by March 17, 2020. The RSV and RV seasonal patterns were similar in all years considered before March 17 (Figure 3, *C* and *D*). RSV was waning by March 17, 2020 (Figure 3, *C*), whereas the 2020 RV season was near its peak on March 17, 2020 (Figure 3, *D*). Controlled interrupted time series results found some significant changes when comparing 2020 data to previous years' data for all 3 of the 4 viruses (not for INF-A), though year-to-year variability was observed, consistent with variable timing of viral seasons (see Figure E1 in this article's Online Repository at www.jaci-inpractice.org). For example, significant differences were identified for RSV in the period before March 17 though some previous years had higher rates of positive testing than in 2020, whereas others had lower (Figure E1, *C*, and Table II). RV was the only virus with significantly decreased levels in the post—March 17, 2020, time period as compared with the same time period during previous years, when years were compared individually or as a 2015 to 2019 historical average (Figure E1, *D*, and Figure 3, *E-G*).

Levels of 4 criteria air pollutants in Philadelphia did not significantly change during the COVID-19 pandemic compared with historical data

Comparison of pre—and post—March 17, 2020 pollution levels (Table III; Figure 4, *A*) found that the daily average of $PM_{2.5}$, PM_{10}, and NO_2 levels decreased by 29.0% (2.17 μg/m^3), 18.2% (3.13 μg/m^3), and 44.1% (6.75 ppb), respectively, whereas ozone levels increased by 43.4% (10.08 ppb). Historical data for the period 2015 to 2019 showed comparable changes pre—and post—Mar 17: AirNow estimates found that $PM_{2.5}$ levels decreased by 34.2% (3.88 μg/m^3) and ozone increased by 52.4% (10.9 ppb); AirData estimates found that $PM_{2.5}$ levels decreased by 29.2% (3.15 μg/m^3), PM_{10} by 11.6% (2.63 μg/m^3), and NO_2 by 28.5% (5.49 ppb), whereas ozone increased by 46.4% (10.69 ppb). Although some of these changes differed

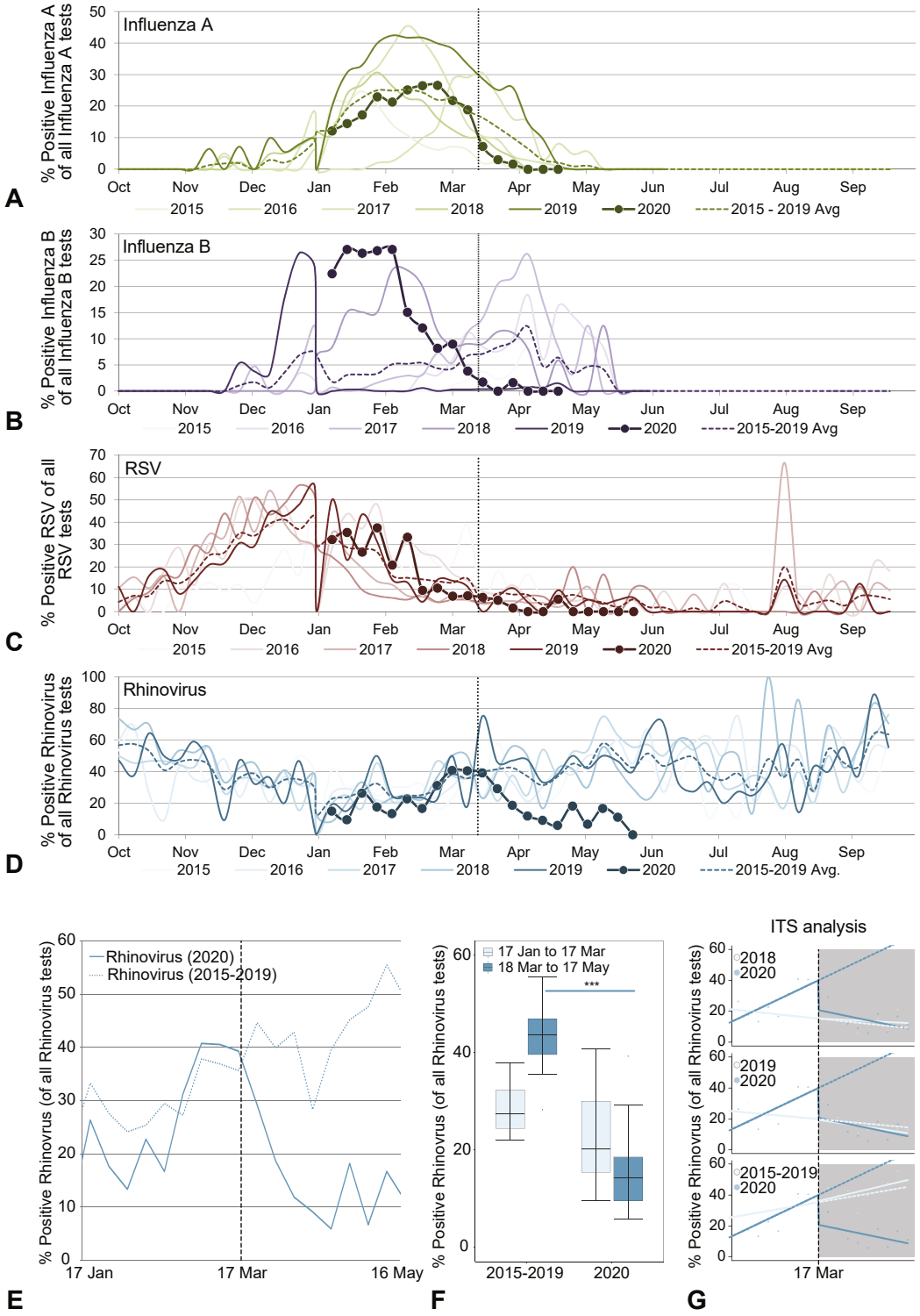

FIGURE 3. Changes in viral respiratory testing during the COVID-19 pandemic. Deidentified institutional ED virology testing results for the period 2015 to 2020 were accessed. (**A-D**) Time series plots comparing historical data (2015-2019) to the current year (2020) for rates of positive IFV-A (*A*), IFV-B (*B*), RV (*C*), and RSV (*D*) testing vs total tests for each virus. (**E**) For 2020, RV testing data from January 17 to March 17 and March 18 to May 17 were compared to averaged historical data from the same dates from 2015 to 2019. (**F**) Bar plots comparing the 2 time periods (January 17 to March 17 and March 18 to May 17) from the averaged historical time period (2015-2019) vs the current year (2020). (**G**) ITS plots comparing time series in 2018, 2019, and 2015 to 2019 averaged vs 2020. For each, the historical data are plotted in a lighter color. The dashed line after week 9 (March 17) is the predicted data based on the previous results, and the uninterrupted line is the actual data from 2020 (exact data also plotted as circles). Significance testing via ANOVA (*F*) and details in Table II for Figure 3, *G*. *ITS*, Interrupted time series.

TABLE II. ITS analysis of viral testing data from CHOP before and after COVID-19 public health interventions were enacted

Years compared	IFV-A	IFV-B	RV	RSV
2015 vs 2020	0.93 (NS)	0.025*	0.0040†	0.016*
2016 vs 2020	0.52 (NS)	0.0007‡	0.021*	0.0008‡
2017 vs 2020	0.59 (NS)	0.014*	0.0006‡	0.0290*
2018 vs 2020	0.89 (NS)	0.037*	0.0035†	0.023*
2019 vs 2020	0.81 (NS)	0.011*	0.011*	0.0057†
2015-2019 vs 2020	0.79 (NS)	2.5×10^{-06}‡	0.0074†	0.14 (NS)

ITS, Interrupted time series; *NS*, not significant.
*$P \leq .05$.
†$P \leq .01$.
‡$P \leq .001$.

TABLE III. Mean measures of 4 criteria air pollutants in Philadelphia before and after COVID-19 public health interventions were enacted

	AirData (2015-2019)		AirNow (2015-2019)		AirNow (2020)	
Air pollutant	January 17 to March 17	March 18 to May 17	January 17 to March 17	March 18 to May 17	January 17 to March 17	March 18 to May 17
NO_2 (ppb)	19.2 ± 6.8	13.7 ± 4.6	NA	NA	15.2 ± 7.6	8.5 ± 3.8
Ozone (ppb)	23.0 ± 6.5	33.7 ± 4.9	20.8 ± 5.8	31.7 ± 3.6	23.2 ± 8.5	33.2 ± 5.2
$PM_{2.5}$ ($\mu g/m^3$)	10.7 ± 3.5	7.6 ± 2.5	11.3 ± 2.4	7.4 ± 1.7	7.3 ± 4.3	5.2 ± 2.2
PM_{10} ($\mu g/m^3$)	22.7 ± 3.4	20.1 ± 3.0	NA	NA	17.2 ± 7.7	14.0 ± 4.7

NA, Not available; *ppb*, parts per billion.
Values are mean ± SD.

significantly across the full range of days (January 17 to May 17), year, and/or before and after the March 17 date, none of the changes were statistically significant compared with historical trends observed across the pre—and post—March 17 60-day time period (see Table E3 in this article's Online Repository at www.jaci-inpractice.org). Specifically, $PM_{2.5}$ and PM_{10} had significantly decreased levels in 2020 compared with previous years during the days January 17 to May 17; $PM_{2.5}$ significantly decreased after March 17 in all years whether using AirNow or AirData historical data ($P < .05$); ozone had significantly higher levels after March 17 and across all days whether using AirNow or AirData historical data ($P < .001$); and NO_2 significantly decreased across days ($P < .05$) with no change before or after March 17 or by year. Figure 4, *B*, shows the raster of $PM_{2.5}$ levels in Philadelphia for the 60-day pre—and post—March 17 periods along with the location of air monitoring stations that recorded $PM_{2.5}$ measures.

DISCUSSION

We found that public health interventions designed to limit SARS-CoV-2 transmission in the Philadelphia region were associated with increased VTM and decreased overall asthma encounters, systemic steroid prescriptions, and RV positivity in our ED (Figure 5). We previously noted an overall decrease in ED utilization at CHOP,[32] a pattern consistent with that observed in other regions of the country, which included a shift away from in-person care and toward VTM-based care.[33] Our observed decrease in the overall asthma disease burden is also consistent with national survey data.[33]

After March 17, 2020, VTM became the most used asthma encounter modality at CHOP, enabling patients with asthma to access care while adhering to stay-at-home guidelines. Previous studies have demonstrated the utility of VTM to facilitate care delivery to underserved rural populations and as a viable substitute for both routine and acute in-person asthma care visits.[34,35] However, the rapid introduction of VTM across the country represents a new, and as such, understudied care model. Black children accounted for the majority of outpatient and hospital care after March 17, 2020, yet they represented only 26% of VTM encounters. We were unable to determine whether this observed difference by race in VTM care was due to patient preference, differences in access to VTM, or some other factor. Future studies should consider this issue carefully in light of well-known disparities in asthma prevalence, severity, and exacerbations by race, ethnicity, and socioeconomic status in the United States,[36-38] as well as concern for a potential "digital divide" in telemedicine.[39-41]

Changes in respiratory virus infection rates may have contributed to the decrease in asthma encounters we observed. Most notably, we found that cases of positive RV testing decreased after the introduction of public health interventions designed to limit viral transmission of SARS-CoV-2. This is relevant because RV is a key cause of asthma exacerbations.[10,11] The other 3 viruses examined (IFV-A, IFV-B, RSV) were waning by March 17, 2020, and as such likely did not play as active a role in asthma exacerbations that occurred after this date. However, we note that we were limited when comparing viral data trends across years because of variability in seasonal onset and peak timing. This variability led to mixed results on the impact of COVID-19 public health interventions on RSV. Overall, a clinically impactful effect of COVID-19—related public health interventions on RSV was unlikely, although the decrease in RV may have contributed to a decrease in asthma exacerbations after March 17.

Air pollution levels are known to vary according to season: $PM_{2.5}$ and PM_{10} concentrations across the United States are relatively higher in summer and lower in winter,[42] whereas ground-level ozone and NO_2 are inversely related, with levels peaking in summer and winter, respectively.[43] Our results for

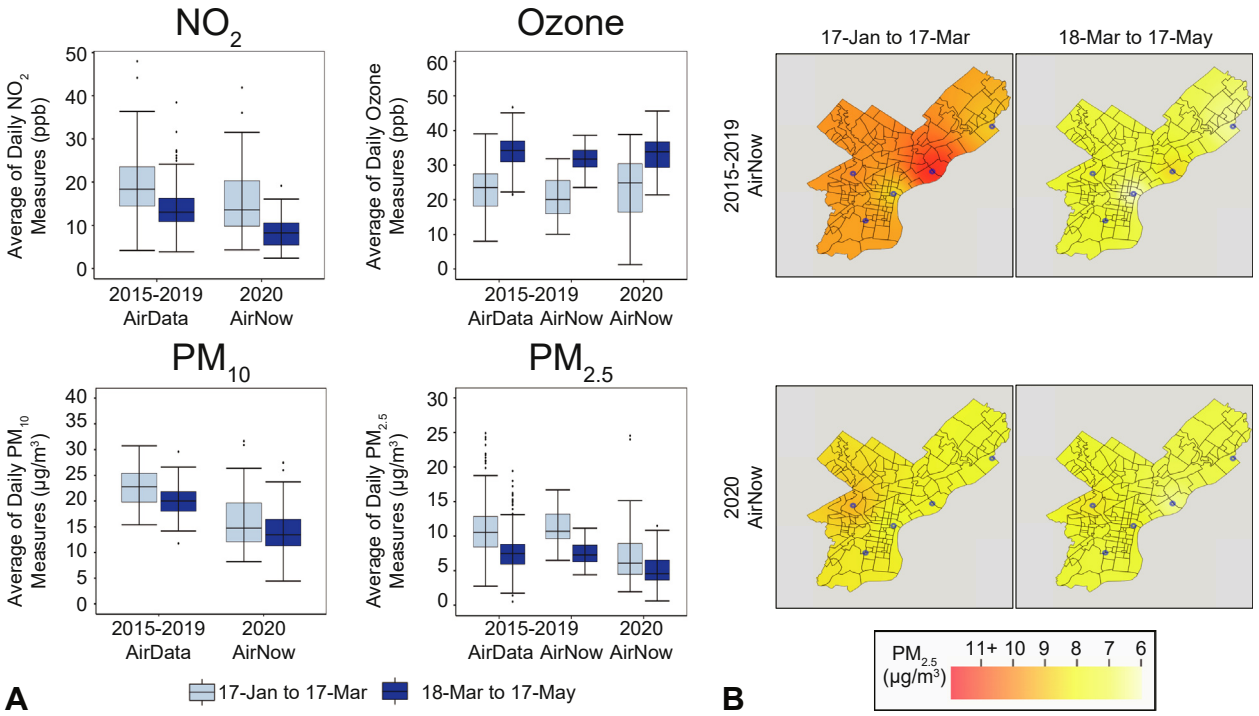

FIGURE 4. Levels of 4 criteria air pollutants in Philadelphia before and after COVID-19 public health interventions were enacted. **(A)** Boxplots of averages of daily NO_2, ozone, PM_{10}, and $PM_{2.5}$ measures corresponding to years 2020 and 2015 to 2019 sourced from AirData and AirNow for the 60-day time period before and after March 17, the day in 2020 when COVID-19 public health interventions were enacted in Philadelphia. None of the changes across March 17 were significantly different in the year 2020 compared with historical years. **(B)** Philadelphia raster layer maps showing daily average $PM_{2.5}$ levels before and after the COVID-19 public health interventions were enacted for the year 2020 and the average of years 2015 to 2019 using AirNow data. The blue circles denote available air monitoring sites. *ppb*, Parts per billion.

each of these 4 criteria air pollutants across the January 17 to May 17 time frame in Philadelphia are consistent with known seasonal trends. Although we did not observe statistically significant changes after COVID-19 public health interventions for these 4 pollutants, the dramatic reduction in vehicular traffic and some industrial activity likely reduced levels of specific pollutants not captured by EPA regulatory monitors. NO_2 and PM_{10} comparisons were limited because they involved 2 different sources of data: AirNow and AirData. Although the same monitoring sites provided data to these publicly available resources, they differed in that AirData releases quality-assured data, whereas AirNow releases real-time measures. Hence, only AirNow contained 2020 measures, whereas only AirData contained complete historical measures. This limitation would likely not change our conclusions because comparison of $PM_{2.5}$ and ozone measures derived from AirNow and AirData for the period 2015 to 2019 revealed that they were broadly similar. In addition, controlled interrupted time series results were similar whether AirNow or AirData historical measures were used for these 2 pollutants (Table E2). Our pollution results were also limited because they relied on measures taken at specific monitoring sites that may not have adequately captured differences experienced by individuals across the greater Philadelphia region. In addition to potentially changing levels of outdoor air pollutants, COVID-19–related public health interventions likely influenced pollution exposure profiles of children in other ways, including via decreased commuting and outdoor activity.

An additional factor that may have contributed to the reduced asthma disease burden and health care utilization after COVID-19 public health interventions were introduced is increased implementation of preventative measures. For example, some providers may have purposefully reached out to patients' families to encourage filling controller medication prescriptions as the COVID-19 pandemic began, given initial concern that those with asthma had increased susceptibility to more severe outcomes with SARS-CoV-2 infection. In addition, fear of contracting COVID-19 may have reduced the likelihood of an individual accessing in-person care, as well as increased adherence to controller medications.[44] Finally, just as social distancing and increased time spent indoors may have limited patient exposure to viruses and outdoor pollution, these measures may have also decreased exposure to outdoor environmental allergens that are known triggers of pediatric asthma.[45] School closures may have additionally resulted in reduced exposure to allergens because school environments can be sources of allergens that increase asthma morbidity.[46,47]

Our study is subject to additional limitations worth noting. The demographic, health care utilization, and viral testing data were derived from a single institution and collected as part of routine care. Therefore, our results may not generalize to other

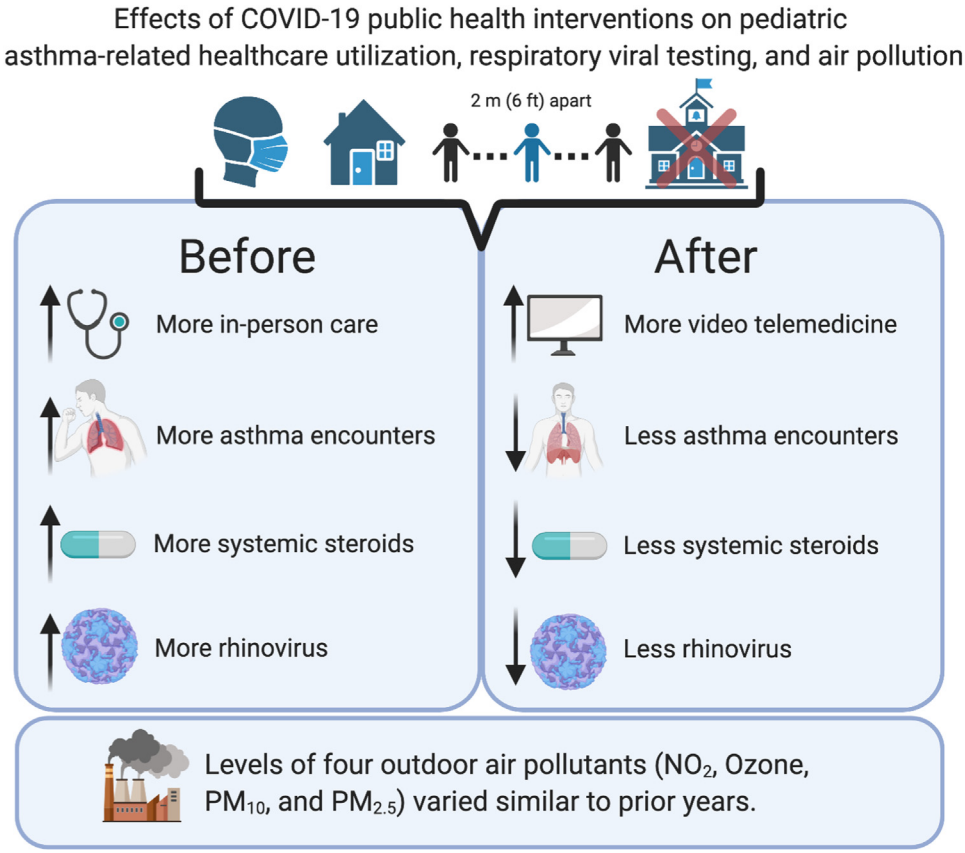

FIGURE 5. Effects of public health interventions designed to limit viral transmission on asthma features. Public health interventions designed to limit viral transmission (masking, social distancing, school closures, etc) were associated with a restructuring of asthma care delivery including a reduction in in-person encounters and an increase in VTM-based care. Overall asthma encounters were reduced, as were systemic steroid prescriptions. Changes in RV infections, but not pollution levels, may have contributed to these trends.

regions and are observational in nature. We relied on primary *International Classification of Diseases* codes to identify asthma encounters, which may be affected by billing or administrative constraints, and hence may have introduced bias in our data collection. Our prescription data are incomplete in that patients may have sought care outside of our network, and it is limited in that we do not have information on prescriptions filled or adherence. Furthermore, we observed an increase in steroid prescriptions in 2020 as compared with previous years. This increase could be due to shifts in patient acuity, or provider prescription practices. Finally, use of electronic health record–derived data is subject to bias and error more broadly, which we were unable to control for, although most errors in the data would have biased us toward not observing significant changes. As such, future studies are warranted to refine our findings and improve our understanding of the effects of the COVID-19 pandemic on asthma care, triggers, and clinical outcomes.

Acknowledgments

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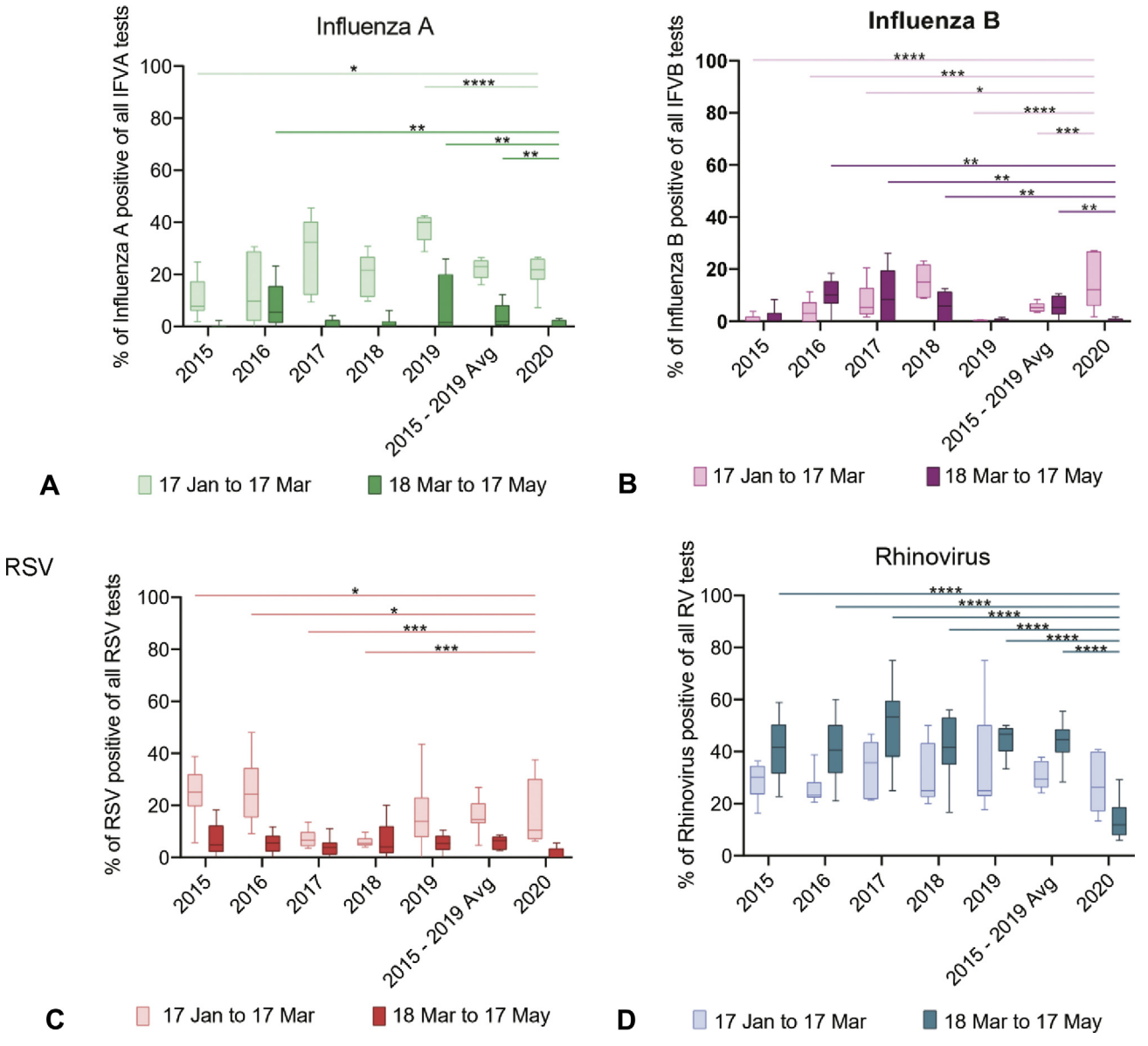

FIGURE E1. Effects of public health interventions designed to limit viral transmission on viral testing. Deidentified institutional ED virology testing results for the period 2015 to 2020 were accessed. (**A**-**D**) Bar plots of rates of positive viral testing (IFV-A, IFV-B, RSV, and RV, respectively) from January 17 to March 17 vs March 18 to May 17 in the period 2015 to 2019 (and the average of that range) vs 2020.

TABLE E1. Asthma medication classes

Medicine ID no.	Name	Class
61180	Decadron IJ	Systemic steroid
61181	Decadron IV	Systemic steroid
61183	Decadron OR	Systemic steroid
132559	DEX Combo 8-4 mg/mL IJ SUSP	Systemic steroid
132710	DEX Combo IJ	Systemic steroid
132560	DEX LA 16 16 mg/mL IJ SUSP	Systemic steroid
132711	DEX LA 16 IJ	Systemic steroid
132561	DEX LA 8 8 mg/mL IJ SUSP	Systemic steroid
132712	DEX LA 8 IJ	Systemic steroid
130359	Dexameth SOD PHOS-BUPIV-LIDO	Systemic steroid
90302	Dexamethasone (glucocorticosteroids)	Systemic steroid
61547	Dexamethasone (PAK) OR	Systemic steroid
200200162	Dexamethasone 0.1 mg/mL (D5W) injection custom	Systemic steroid
200200163	Dexamethasone 0.1 mg/mL (NSS) injection custom	Systemic steroid
2762	Dexamethasone 0.5 mg OR TABS	Systemic steroid
200200499	Dexamethasone 0.5 mg OR TABS (CHEMO)	Systemic steroid
2759	Dexamethasone 0.5 mg/5 mL OR ELIX	Systemic steroid
2760	Dexamethasone 0.5 mg/5 mL OR SOLN	Systemic steroid
2763	Dexamethasone 0.75 mg OR TABS	Systemic steroid
2764	Dexamethasone 1 mg OR TABS	Systemic steroid
200201009	Dexamethasone 1 mg OR TABS (CHEMO)	Systemic steroid
200200164	Dexamethasone 1 mg/mL (D5W) injection custom	Systemic steroid
200200874	Dexamethasone 1 mg/mL (NSS) injection custom	Systemic steroid
21292	Dexamethasone 1 mg/mL OR CONC	Systemic steroid
200200501	Dexamethasone 1 mg/mL OR CONC (CHEMO)	Systemic steroid
135377	Dexamethasone 1.5 mg (21) OR TBPK	Systemic steroid
135378	Dexamethasone 1.5 mg (35) OR TBPK	Systemic steroid
135379	Dexamethasone 1.5 mg (51) OR TBPK	Systemic steroid
2765	Dexamethasone 1.5 mg OR TABS	Systemic steroid
200200502	Dexamethasone 1.5 mg OR TABS (CHEMO)	Systemic steroid
2766	Dexamethasone 2 mg OR TABS	Systemic steroid
200201008	Dexamethasone 2 mg OR TABS (CHEMO)	Systemic steroid
2767	Dexamethasone 4 mg OR TABS	Systemic steroid
200200503	Dexamethasone 4 mg OR TABS (CHEMO)	Systemic steroid
200200504	Dexamethasone 4 mg/mL (undiluted) injection (CHEMO) custom	Systemic steroid
200200165	Dexamethasone 4 mg/mL (undiluted) injection custom	Systemic steroid
2768	Dexamethasone 6 mg OR TABS	Systemic steroid
200200505	Dexamethasone 6 mg OR TABS (CHEMO)	Systemic steroid
132777	Dexamethasone ACE & SOD PHOS	Systemic steroid
132551	Dexamethasone ACE & SOD PHOS 8-4 mg/mL IJ SUSP	Systemic steroid
132713	Dexamethasone ACE & SOD PHOS IJ	Systemic steroid
90303	Dexamethasone acetate	Systemic steroid
29197	Dexamethasone acetate 16 mg/mL IJ SUSP	Systemic steroid
2769	Dexamethasone acetate 8 mg/mL IJ SUSP	Systemic steroid
61549	Dexamethasone acetate IJ	Systemic steroid
2770	Dexamethasone acetate POWD	Systemic steroid
27267	Dexamethasone base POWD	Systemic steroid
200200166	Dexamethasone injection custom orderable	Systemic steroid
200200506	Dexamethasone injection custom orderable (CHEMO)	Systemic steroid
2758	Dexamethasone Intensol 1 mg/mL OR CONC	Systemic steroid
61551	Dexamethasone Intensol OR	Systemic steroid
61554	Dexamethasone OR	Systemic steroid
18270	Dexamethasone POWD	Systemic steroid
130355	Dexamethasone SOD PHOS & BUPIV	Systemic steroid
130356	Dexamethasone SOD PHOS-LIDO	Systemic steroid
121371	Dexamethasone SOD Phosphate PF 10 mg/mL IJ SOLN	Systemic steroid
121730	Dexamethasone SOD Phosphate PF IJ	Systemic steroid
200201236	Dexamethasone sodium phosphate (CHEMO) 4 mg/mL IJ SOLN	Systemic steroid

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
90304	Dexamethasone sodium phosphate (glucocorticosteroids)	Systemic steroid
2771	Dexamethasone sodium phosphate 10 mg/mL IJ SOLN	Systemic steroid
200201160	Dexamethasone sodium phosphate 10 mg/mL IJ SOLN (CHEMO)	Systemic steroid
128185	Dexamethasone sodium phosphate 100 mg/10 mL IJ SOLN	Systemic steroid
128184	Dexamethasone sodium phosphate 120 mg/30 mL IJ SOLN	Systemic steroid
128183	Dexamethasone sodium phosphate 20 mg/5 mL IJ SOLN	Systemic steroid
2772	Dexamethasone sodium phosphate 4 mg/mL IJ SOLN	Systemic steroid
200201065	Dexamethasone sodium phosphate 4 mg/mL INH SOLN custom	Systemic steroid
61557	Dexamethasone sodium phosphate IJ	Systemic steroid
61558	Dexamethasone sodium phosphate IV	Systemic steroid
2776	Dexamethasone sodium phosphate POWD	Systemic steroid
135753	DEXPAK 10 DAY 1.5 mg (35) OR TBPK	Systemic steroid
97925	DEXPAK 10 DAY OR	Systemic steroid
135749	DEXPAK 13 DAY 1.5 mg (51) OR TBPK	Systemic steroid
61586	DEXPAK 13 DAY OR	Systemic steroid
135755	DEXPAK 6 DAY 1.5 mg (21) OR TBPK	Systemic steroid
100127	DEXPAK 6 DAY OR	Systemic steroid
130145	Doubledex 10 mg/mL IJ KIT	Systemic steroid
130264	Doubledex IJ	Systemic steroid
70802	Medrol (PAK) OR	Systemic steroid
17892	Medrol 16 mg OR TABS	Systemic steroid
5790	Medrol 2 mg OR TABS	Systemic steroid
5792	Medrol 32 mg OR TABS	Systemic steroid
17891	Medrol 4 mg OR TABS	Systemic steroid
135742	Medrol 4 mg OR TBPK	Systemic steroid
5793	Medrol 8 mg OR TABS	Systemic steroid
70803	Medrol OR	Systemic steroid
71141	Methylpred 40 IJ	Systemic steroid
130360	Methylprednisol & BUPIV & LIDO	Systemic steroid
90309	Methylprednisolone	Systemic steroid
128079	Methylprednisolone & lidocaine IJ	Systemic steroid

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
200200507	Methylprednisolone (CHEMO) injection custom orderable	Systemic steroid
71143	Methylprednisolone (PAK) OR	Systemic steroid
5957	Methylprednisolone 16 mg OR TABS	Systemic steroid
12408	Methylprednisolone 2 mg OR TABS	Systemic steroid
12410	Methylprednisolone 32 mg OR TABS	Systemic steroid
5958	Methylprednisolone 4 mg OR TABS	Systemic steroid
135372	Methylprednisolone 4 mg OR TBPK	Systemic steroid
12411	Methylprednisolone 8 mg OR TABS	Systemic steroid
128116	Methylprednisolone ACE-LIDO	Systemic steroid
132562	Methylprednisolone ACE-LIDO 40-10 mg/mL IJ SUSP	Systemic steroid
132542	Methylprednisolone ACE-LIDO 80-10 mg/mL IJ SUSP	Systemic steroid
132732	Methylprednisolone ACE-LIDO IJ	Systemic steroid
90310	Methylprednisolone acetate	Systemic steroid
132539	Methylprednisolone acetate 100 mg/mL IJ SUSP	Systemic steroid
5959	Methylprednisolone acetate 20 mg/mL IJ SUSP	Systemic steroid
5959	Methylprednisolone acetate 40 mg/mL IJ SUSP	Systemic steroid
200201903	Methylprednisolone acetate 40 mg/mL IJ SUSP (IR use only) C	Systemic steroid
5961	Methylprednisolone acetate 80 mg/mL IJ SUSP	Systemic steroid
71145	Methylprednisolone acetate IJ	Systemic steroid
121372	Methylprednisolone acetate PF 40 mg/mL IJ SUSP	Systemic steroid
121373	Methylprednisolone acetate PF 80 mg/mL IJ SUSP	Systemic steroid
121778	Methylprednisolone acetate PF IJ	Systemic steroid
20399	Methylprednisolone acetate POWD	Systemic steroid
200200293	Methylprednisolone injection custom orderable	Systemic steroid

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
71147	Methylprednisolone OR	Systemic steroid
20398	Methylprednisolone POWD	Systemic steroid
200200508	Methylprednisolone sodium Succ (CHEMO) 1 mg/mL (NSS) INJECT	Systemic steroid
200200509	Methylprednisolone sodium Succ (CHEMO) 1000 mg IJ SOLR	Systemic steroid
200200510	Methylprednisolone sodium Succ (CHEMO) 125 mg IJ SOLR	Systemic steroid
200201004	Methylprednisolone sodium Succ (CHEMO) 125 mg/mL (SWFI) INJ	Systemic steroid
200200511	Methylprednisolone sodium Succ (CHEMO) 40 mg IJ SOLR	Systemic steroid
200201002	Methylprednisolone sodium Succ (CHEMO) 40 mg/mL (SWFI) INJ	Systemic steroid
90311	Methylprednisolone sodium Succ (glucocorticosteroids)	Systemic steroid
52078	Methylprednisolone sodium Succ 1 g IJ SOLR	Systemic steroid
200200294	Methylprednisolone sodium Succ 1 mg/mL (NSS) Injection CUST	Systemic steroid
12412	Methylprednisolone sodium Succ 1000 mg IJ SOLR	Systemic steroid
12413	Methylprednisolone sodium Succ 125 mg IJ SOLR	Systemic steroid
200201001	Methylprednisolone sodium Succ 125 mg/mL (SWFI) Injection C	Systemic steroid
12414	Methylprednisolone sodium Succ 2000 mg IJ SOLR	Systemic steroid
12415	Methylprednisolone sodium Succ 40 mg IJ SOLR	Systemic steroid
200200999	Methylprednisolone sodium SUCC 40 mg/mL (SWFI) injection CU	Systemic steroid
12416	Methylprednisolone sodium Succ 500 mg IJ SOLR	Systemic steroid
71149	Methylprednisolone sodium Succ IJ	Systemic steroid
89026	Millipred 10 mg/5 mL OR SOLN	Systemic steroid
97492	Millipred 5 mg OR TABS	Systemic steroid
135762	Millipred DP 12-DAY 5 mg (48) OR TBPK	Systemic steroid
111603	Millipred DP 12-DAY OR	Systemic steroid
135756	Millipred DP 5 MG (21) OR TBPK	Systemic steroid
135757	Millipred DP 5 mg (48) OR TBPK	Systemic steroid
100265	Millipred DP OR	Systemic steroid
89183	Millipred OR	Systemic steroid
33929	Orapred 15 mg/5 mL OR SOLN	Systemic steroid
51263	Orapred ODT 10 mg OR TBDP	Systemic steroid
50493	Orapred ODT 15 mg OR TBDP	Systemic steroid
51264	Orapred ODT 30 mg OR TBDP	Systemic steroid
73649	Orapred ODT OR	Systemic steroid
73650	ORAPRED OR	Systemic steroid
97196	Pediapred 6.7 (5 mg prednisolone base) mg/5 mL OR SOLN	Systemic steroid
74412	Pediapred OR	Systemic steroid
90312	Prednisolone	Systemic steroid
100776	Prednisolone 15 mg/5 mL OR SOLN	Systemic steroid
13018	Prednisolone 15 mg/5 mL OR SYRP	Systemic steroid
135373	Prednisolone 5 mg (21) OR TBPK	Systemic steroid
135374	Prednisolone 5 mg (48) OR TBPK	Systemic steroid
7711	Prednisolone 5 mg OR TABS	Systemic steroid
90313	Prednisolone acetate (glucocorticosteroids)	Systemic steroid
108953	Prednisolone acetate 16.7 (15 mg base) mg/5 mL OR SUSP	Systemic steroid
75589	Prednisolone acetate IJ	Systemic steroid
109427	Prednisolone acetate OR	Systemic steroid
7716	Prednisolone acetate POWD	Systemic steroid
20923	Prednisolone anhydrous POWD	Systemic steroid
75593	Prednisolone OR	Systemic steroid
7712	Prednisolone POWD	Systemic steroid
75595	Prednisolone SOD phosphate OR	Systemic steroid
90314	Prednisolone sodium phosphate (glucocorticosteroids)	Systemic steroid

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
51252	Prednisolone sodium phosphate 10 mg OR TBDP	Systemic steroid
89025	Prednisolone sodium phosphate 10 mg/5 mL OR SOLN	Systemic steroid
50481	Prednisolone sodium phosphate 15 mg OR TBDP	Systemic steroid
200201856	Prednisolone sodium phosphate 15 mg/5 mL (SWISH & SPIT) OR S	Systemic steroid
33930	Prednisolone sodium phosphate 15 mg/5 mL OR SOLN	Systemic steroid
200200533	Prednisolone sodium phosphate 15 mg/5 mL OR SOLN (CHEMO) Cus	Systemic steroid
97477	Prednisolone sodium phosphate 20 mg/5 mL OR SOLN	Systemic steroid
121526	Prednisolone sodium phosphate 25 mg/5 mL OR SOLN	Systemic steroid
51253	Prednisolone sodium phosphate 30 mg OR TBDP	Systemic steroid
96082	Prednisolone sodium phosphate 6.7 (5 mg base) mg/5 mL OR SOLN	Systemic steroid
75598	Prednisolone sodium phosphate OR	Systemic steroid
20439	Prednisolone sodium phosphate POWD	Systemic steroid
90315	Prednisone	Systemic steroid
75601	Prednisone (PAK) OR	Systemic steroid
200200351	Prednisone 0.5 mg/mL OR SOL custom	Systemic steroid
7721	Prednisone 1 mg OR TABS	Systemic steroid
200200492	Prednisone 1 mg OR TABS (CHEMO) custom	Systemic steroid
120527	Prednisone 1 mg OR TBEC	Systemic steroid
135431	Prednisone 10 mg (21) OR TBPK	Systemic steroid
135432	Prednisone 10 mg (48) OR TBPK	Systemic steroid
7722	Prednisone 10 mg OR TABS	Systemic steroid
200200493	Prednisone 10 mg OR TABS (CHEMO) custom	Systemic steroid
120528	Prednisone 2 mg OR TBEC	Systemic steroid
7723	Prednisone 2.5 mg OR TABS	Systemic steroid
200200494	Prednisone 2.5 mg OR TABS (CHEMO) custom	Systemic steroid
7724	Prednisone 20 mg OR TABS	Systemic steroid
200200495	Prednisone 20 mg OR TABS (CHEMO) custom	Systemic steroid
135375	Prednisone 5 mg (21) OR TBPK	Systemic steroid
135376	Prednisone 5 mg (48) OR TBPK	Systemic steroid
7725	Prednisone 5 mg OR TABS	Systemic steroid
200200496	Prednisone 5 mg OR TABS (CHEMO) custom	Systemic steroid
120529	Prednisone 5 mg OR TBEC	Systemic steroid
7720	Prednisone 5 mg/5 mL OR SOLN	Systemic steroid
7718	Prednisone 5 mg/mL OR CONC	Systemic steroid
7726	Prednisone 50 mg OR TABS	Systemic steroid
22674	Prednisone intensol 5 mg/mL OR CONC	Systemic steroid
75602	Prednisone Intensol OR	Systemic steroid
75603	Prednisone OR	Systemic steroid
7727	Prednisone POWD	Systemic steroid
7732	Prelone 15 mg/5 mL OR SYRP	Systemic steroid
75620	Prelone OR	Systemic steroid
8767	Solu-Medrol 1000 mg IJ SOLR	Systemic steroid
8768	Solu-Medrol 125 mg IJ SOLR	Systemic steroid
8769	Solu-Medrol 2 g IJ SOLR	Systemic steroid
8770	Solu-Medrol 40 mg IJ SOLR	Systemic steroid
8771	Solu-Medrol 500 mg IJ SOLR	Systemic steroid
79793	Solu-Medrol IJ	Systemic steroid
79797	Solurex IJ	Systemic steroid
79798	Solurex LA IJ	Systemic steroid
80064	Sterapred 12 DAY OR	Systemic steroid
80065	Sterapred DS 12 DAY OR	Systemic steroid
80066	Sterapred DS OR	Systemic steroid
80067	Sterapred OR	Systemic steroid
36549	Accuneb 0.63 mg/3 mL IN NEBU	Beta-agonist
36550	Accuneb 1.25 mg/3 mL IN NEBU	Beta-agonist
53821	Accuneb IN	Beta-agonist
54377	Airet IN	Beta-agonist
91225	Albuterol	Beta-agonist

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
54543	Albuterol IN	Beta-agonist
20261	Albuterol POWD	Beta-agonist
91226	Albuterol sulfate	Beta-agonist
311	Albuterol sulfate (2.5 mg/3 mL) 0.083% IN NEBU	Beta-agonist
312	Albuterol sulfate (5 mg/mL) 0.5% IN NEBU	Beta-agonist
200200745	Albuterol sulfate (5 mg/mL) 0.5% NEB continuous custom	Beta-agonist
36541	Albuterol sulfate 0.63 mg/3 mL IN NEBU	Beta-agonist
36542	Albuterol sulfate 1.25 mg/3 mL IN NEBU	Beta-agonist
132129	Albuterol sulfate 108 (90 µg base) µg/ACT IN AEPB	Beta-agonist
315	Albuterol sulfate 2 mg OR TABS	Beta-agonist
314	Albuterol sulfate 2 mg/5 mL OR SYRP	Beta-agonist
316	Albuterol sulfate 4 mg OR TABS	Beta-agonist
39219	Albuterol sulfate ER 4 mg OR TB12	Beta-agonist
39220	Albuterol sulfate ER 8 mg OR TB12	Beta-agonist
123418	Albuterol sulfate ER OR	Beta-agonist
21155	Albuterol sulfate HFA 108 (90 µg base) µg/ACT IN AERS	Beta-agonist
200200995	Albuterol sulfate HFA 108 (90 µg base) µg/ACT IN AERS (ED HOM)	Beta-agonist
200200994	Albuterol sulfate HFA 108 (90 µg base) µg/ACT IN AERS (OR Use)	Beta-agonist
98773	Albuterol sulfate HFA IN	Beta-agonist
54545	Albuterol sulfate IN	Beta-agonist
54546	Albuterol sulfate OR	Beta-agonist
317	Albuterol sulfate POWD	Beta-agonist
2002001992	Albuterol sulfate variable dose for Pyxis	Beta-agonist
91234	Levalbuterol HCL (sympathomimetics)	Beta-agonist
37337	Levalbuterol HCL 0.31 mg/3 mL IN NEBU	Beta-agonist
29159	Levalbuterol HCL 0.63 mg/3 mL IN NEBU	Beta-agonist
44604	Levalbuterol HCL 1.25 mg/0.5 mL IN NEBU	Beta-agonist
29160	Levalbuterol HCL 1.25 mg/3 mL IN NEBU	Beta-agonist
69516	Levalbuterol HCL IN	Beta-agonist
91235	Levalbuterol tartrate	Beta-agonist
49020	Levalbuterol tartrate 45 µg/ACT IN AERO	Beta-agonist
69517	Levalbuterol tartrate IN	Beta-agonist
50377	Proair HFA 108 (90 µg base) µg/ACT IN AERS	Beta-agonist
75956	Proair HFA IN	Beta-agonist
132126	Proair respiclick 108 (90 µg base) µg/ACT IN AEPB	Beta-agonist
132374	Proair respiclick IN	Beta-agonist
21277	Proventil HFA 108 (90 µg base) µg/ACT IN AERS	Beta-agonist
76250	Proventil HFA IN	Beta-agonist
76251	Proventil IN	Beta-agonist
76252	Proventil OR	Beta-agonist
200200406	Terbutaline 0.1% nebulization SOLN custom	Beta-agonist
91239	Terbutaline sulfate	Beta-agonist
200200937	Terbutaline sulfate 0.1 mg/mL IJ SOLN custom	Beta-agonist
13430	Terbutaline sulfate 1 mg/mL IJ SOLN	Beta-agonist
200201165	Terbutaline sulfate 1 mg/mL IJ SOLN (subcutaneous use only)	Beta-agonist
200200407	Terbutaline sulfate 1 mg/mL SUSP custom	Beta-agonist
13432	Terbutaline sulfate 2.5 mg OR TABS	Beta-agonist
13433	Terbutaline sulfate 5 mg OR TABS	Beta-agonist
81143	Terbutaline sulfate IJ	Beta-agonist
200200938	Terbutaline sulfate injection custom orderable	Beta-agonist
81144	Terbutaline sulfate OR	Beta-agonist
20433	Terbutaline sulfate POWD	Beta-agonist
37396	Xopenex 0.31 mg/3 mL IN NEBU	Beta-agonist
29270	Xopenex 0.63 mg/3 mL IN NEBU	Beta-agonist
29271	Xopenex 1.25 mg/3 mL IN NEBU	Beta-agonist
44598	Xopenex concentrate 1.25 mg/0.5 mL IN NEBU	Beta-agonist
83997	Xopenex concentrate IN	Beta-agonist
49017	Xopenex HFA 45 µg/ACT IN AERO	Beta-agonist
83998	Xopenex HFA IN	Beta-agonist
83999	Xopenex IN	Beta-agonist
54262	Aerobid IN	ICS
54263	Aerobid-M IN	ICS

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
127561	Aerospan 80 μg/ACT IN AERS	ICS
127718	Aerospan IN	ICS
96592	Alvesco 160 μg/ACT IN AERS	ICS
96591	Alvesco 80 μg/ACT IN AERS	ICS
97729	Alvesco IN	ICS
130919	Arnuity Ellipta 100 μg/ACT IN AEPB	ICS
130920	Arnuity Ellipta 200 μg/ACT IN AEPB	ICS
130972	Arnuity Ellipta IN	ICS
47449	Asmanex 120 metered doses 220 μg/INH IN AEPB	ICS
55726	Asmanex 120 metered doses IN	ICS
47450	Asmanex 14 metered doses 220 μg/INH IN AEPB	ICS
55727	Asmanex 14 metered doses IN	ICS
89591	Asmanex 30 metered doses 110 μg/INH IN AEPB	ICS
47447	Asmanex 30 metered doses 220 μg/INH IN AEPB	ICS
55728	Asmanex 30 metered doses IN	ICS
47448	Asmanex 60 metered doses 220 μg/INH IN AEPB	ICS
55729	Asmanex 60 metered doses IN	ICS
111284	Asmanex 7 metered doses 110 μg/INH IN AEPB	ICS
111529	Asmanex 7 metered doses IN	ICS
130881	Asmanex HFA 100 μg/ACT IN AERO	ICS
130893	Asmanex HFA 200 μg/ACT IN AERO	ICS
130973	Asmanex HFA IN	ICS
56112	Azmacort IN	ICS
91254	Beclomethasone dipropionate (steroid inhalants)	ICS
33588	Beclomethasone dipropionate 40 μg/ACT IN AERS	ICS
33589	Beclomethasone dipropionate 80 μg/ACT IN AERS	ICS
56626	Beclomethasone dipropionate IN	ICS
56627	Beclovent IN	ICS

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
91255	Budesonide (steroid inhalants)	ICS
33341	Budesonide 0.25 mg/2 mL IN SUSP	ICS
33342	Budesonide 0.5 mg/2 mL IN SUSP	ICS
200201034	Budesonide 0.5 mg/2 mL NEB for *po* use	ICS
85108	Budesonide 1 mg/2 mL IN SUSP	ICS
98957	Budesonide 180 μg/ACT IN AEPB	ICS
98956	Budesonide 90 μg/ACT IN AEPB	ICS
98788	Budesonide IN	ICS
98448	Ciclesonide (steroid inhalants)	ICS
96103	Ciclesonide 160 μg/ACT IN AERS	ICS
96102	Ciclesonide 80 μg/ACT IN AERS	ICS
97832	Ciclesonide IN	ICS
98924	Flovent Diskus 100 μg/BLIST IN AEPB	ICS
98925	Flovent Diskus 250 μg/BLIST IN AEPB	ICS
53294	Flovent Diskus 50 μg/BLIST IN AEPB	ICS
64815	Flovent Diskus IN	ICS
46255	Flovent HFA 110 μg/ACT IN AERO	ICS
46256	Flovent HFA 220 μg/ACT IN AERO	ICS
46254	Flovent HFA 44 μg/ACT IN AERO	ICS
64816	Flovent HFA IN	ICS
64817	Flovent IN	ICS
64818	Flovent Rotadisk IN	ICS
91256	Flunisolide (steroid inhalants)	ICS
127699	Flunisolide HFA	ICS
127438	Flunisolide HFA 80 μg/ACT IN AERS	ICS
127758	Flunisolide HFA IN	ICS
64856	Flunisolide IN	ICS
20361	Flunisolide POWD	ICS
131120	Fluticasone furoate (steroid inhalants)	ICS
130716	Fluticasone furoate 100 μg/ACT IN AEPB	ICS
130717	Fluticasone furoate 200 μg/ACT IN AEPB	ICS
131018	Fluticasone furoate IN	ICS
91257	Fluticasone propionate (INHAL)	ICS
32750	Fluticasone propionate (INHAL) 100 μg/BLIST IN AEPB	ICS

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
32751	Fluticasone propionate (INHAL) 250 μg/ BLIST IN AEPB	ICS
32749	Fluticasone propionate (INHAL) 50 μg/BLIST IN AEPB	ICS
64934	Fluticasone propionate (INHAL) IN	ICS
91258	Fluticasone propionate HFA	ICS
46046	Fluticasone propionate HFA 110 μg/ACT IN AERO	ICS
46047	Fluticasone propionate HFA 220 μg/ACT IN AERO	ICS
46045	Fluticasone propionate HFA 44 μg/ACT IN AERO	ICS
134419	Fluticasone propionate HFA IN	ICS
91259	Mometasone furoate (steroid inhalants)	ICS
130882	Mometasone furoate 100 μg/ACT IN AERO	ICS
89590	Mometasone furoate 110 μg/INH IN AEPB	ICS
130883	Mometasone furoate 200 μg/ACT IN AERO	ICS
47345	Mometasone furoate 220 μg/INH IN AEPB	ICS
71565	Mometasone furoate IN	ICS
33535	Pulmicort 0.25 mg/2 mL IN SUSP	ICS
33536	Pulmicort 0.5 mg/2 mL IN SUSP	ICS
85111	Pulmicort 1 mg/2 mL IN SUSP	ICS
99899	Pulmicort flexhaler 180 μg/ACT IN AEPB	ICS
99900	Pulmicort flexhaler 90 μg/ ACT IN AEPB	ICS
76405	Pulmicort flexhaler IN	ICS
76406	Pulmicort IN	ICS
76407	Pulmicort turbuhaler IN	ICS
33585	QVAR 40 μg/ACT IN AERS	ICS
33586	QVAR 80 μg/ACT IN AERS	ICS
76802	QVAR IN	ICS
91260	Triamcinolone acetonide (steroid inhalants)	ICS
85453	Triamcinolone acetonide IN	ICS
83089	Vanceril double strength IN	ICS
83090	Vanceril IN	ICS

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
105585	Advair Diskus 100-50 μg/ dose IN AEPB	ICS + LABA
105588	Advair Diskus 250-50 μg/ dose IN AEPB	ICS + LABA
105589	Advair Diskus 500-50 μg/ dose IN AEPB	ICS + LABA
54204	Advair Diskus IN	ICS + LABA
50623	Advair HFA 115-21 μg/ ACT IN AERO	ICS + LABA
50624	Advair HFA 230-21 μg/ ACT IN AERO	ICS + LABA
50622	Advair HFA 45-21 μg/ ACT IN AERO	ICS + LABA
54205	Advair HFA IN	ICS + LABA
125719	BREO Ellipta 100-25 μg/ INH IN AEPB	ICS + LABA
132901	BREO Ellipta 200-25 μg/ INH IN AEPB	ICS + LABA
125944	BREO Ellipta IN	ICS + LABA
91246	Budesonide-formoterol fumarate	ICS + LABA
53024	Budesonide-formoterol fumarate 160-4.5 μg/ ACT IN AERO	ICS + LABA
53023	Budesonide-formoterol fumarate 80-4.5 μg/ ACT IN AERO	ICS + LABA
57629	Budesonide-formoterol fumarate IN	ICS + LABA
110610	Dulera 100-5 μg/ACT IN AERO	ICS + LABA
110611	Dulera 200-5 μg/ACT IN AERO	ICS + LABA
110811	Dulera IN	ICS + LABA
126085	Fluticasone furoate-Vilanterol	ICS + LABA
125641	Fluticasone furoate-Vilanterol 100-25 μg/ INH IN AEPB	ICS + LABA
132806	Fluticasone furoate-Vilanterol 200-25 μg/ INH IN AEPB	ICS + LABA
125999	Fluticasone furoate-Vilanterol IN	ICS + LABA
91247	Fluticasone-salmeterol	ICS + LABA
105249	Fluticasone-salmeterol 100-50 μg/dose IN AEPB	ICS + LABA
50619	Fluticasone-salmeterol 115-21 μg/ACT IN AERO	ICS + LABA
50620	Fluticasone-salmeterol 230-21 μg/ACT IN AERO	ICS + LABA
105250	Fluticasone-salmeterol 250-50 μg/dose IN AEPB	ICS + LABA

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
50618	Fluticasone-salmeterol 45-21 μg/ACT IN AERO	ICS + LABA
105251	Fluticasone-salmeterol 500-50 μg/dose IN AEPB	ICS + LABA
64938	Fluticasone-salmeterol IN	ICS + LABA
111224	Mometasone furo-formoterol FUM	ICS + LABA
110576	Mometasone furo-formoterol FUM 100-5 μg/ACT IN AERO	ICS + LABA
110577	Mometasone furo-formoterol FUM 200-5 μg/ACT IN AERO	ICS + LABA
110835	Mometasone furo-formoterol FUM IN	ICS + LABA
53239	Symbicort 160-4.5 μg/ACT IN AERO	ICS + LABA
53238	Symbicort 80-4.5 μg/ACT IN AERO	ICS + LABA
80691	Symbicort IN	ICS + LABA
128121	Umeclidinium-Vilanterol	ICS + LABA
127865	UMeclidinium-Vilanterol 62.5-25 μg/INH IN AEPB	ICS + LABA
128105	Umeclidinium-Vilanterol IN	ICS + LABA
30756	Accolate 10 mg OR TABS	Leukotriene modulators
21303	Accolate 20 mg OR TABS	Leukotriene modulators
53764	Accolate OR	Leukotriene modulators
91262	Montelukast sodium (leukotriene modulators)	Leukotriene modulators
26447	Montelukast sodium 10 mg OR TABS	Leukotriene modulators
31645	Montelukast sodium 4 mg OR CHEW	Leukotriene modulators
41211	Montelukast sodium 4 mg OR PKT	Leukotriene modulators
26448	Montelukast sodium 5 mg OR Chew	Leukotriene modulators
71666	Montelukast sodium OR	Leukotriene modulators
26454	Singulair 10 mg OR TABS	Leukotriene modulators
31649	Singulair 4 mg OR Chew	Leukotriene modulators
41210	Singulair 4 mg OR PKT	Leukotriene modulators
26451	Singulair 5 mg OR Chew	Leukotriene modulators
79047	Singulair OR	Leukotriene modulators
91263	Zafirlukast	Leukotriene modulators
30767	Zafirlukast 10 mg OR TABS	Leukotriene modulators
21309	Zafirlukast 20 mg OR TABS	Leukotriene modulators
84136	Zafirlukast OR	Leukotriene modulators
91261	Zileuton	Leukotriene modulators
22305	Zileuton 600 mg OR TABS	Leukotriene modulators
85485	Zileuton ER 600 mg OR TB12	Leukotriene modulators
120894	Zileuton ER OR	Leukotriene modulators
84194	Zileuton OR	Leukotriene modulators
22304	Zyflo 600 mg OR TABS	Leukotriene modulators
85530	Zyflo CR 600 mg OR TB12	Leukotriene modulators
85882	Zyflo CR OR	Leukotriene modulators
84345	Zyflo OR	Leukotriene modulators
134493	Mepolizumab	Biologics
134274	Mepolizumab 100 mg SC SOLR	Biologics
134437	Mepolizumab SC	Biologics
134298	Nucala 100 mg SC SOLR	Biologics
134446	Nucala SC	Biologics
91264	Omalizumab	Biologics
41330	Omalizumab 150 mg SC SOLR	Biologics
73347	Omalizumab SC	Biologics
41342	Xolair 150 mg SC SOLR	Biologics
83995	Xolair SC	Biologics
120900	Aclidinium bromide	Anticholinergics
120515	Aclidinium bromide 400 μg/ACT IN AEPB	Anticholinergics
120732	Aclidinium bromide IN	Anticholinergics
46720	Atrovent HFA 17 μg/ACT IN AERS	Anticholinergics
55931	Atrovent HFA IN	Anticholinergics
55932	Atrovent IN	Anticholinergics
134491	Glycopyrrolate (bronchodilators-anticholinergics)	Anticholinergics
134424	Glycopyrrolate IN	Anticholinergics
130918	Incruse Ellipta 62.5 μg/INH IN AEPB	Anticholinergics
131033	Incruse Ellipta IN	Anticholinergics
91220	Ipratropium bromide (bronchodilators-anticholinergics)	Anticholinergics
14727	Ipratropium bromide 0.02 % IN SOLN	Anticholinergics

(continued)

TABLE E1. *(Continued)*

Medicine ID no.	Name	Class
91221	Ipratropium bromide HFA	Anticholinergics
46527	Ipratropium bromide HFA 17 μg/ACT IN AERS	Anticholinergics
68438	Ipratropium bromide HFA IN	Anticholinergics
68439	Ipratropium bromide IN	Anticholinergics
20367	Ipratropium bromide POWD	Anticholinergics
134455	Seebri Neohaler IN	Anticholinergics
43683	Spiriva Handihaler 18 μg IN CAPS	Anticholinergics
79945	Spiriva Handihaler IN	Anticholinergics
133764	Spiriva Respimat 1.25 μg/ACT IN AERS	Anticholinergics
130566	Spiriva Respimat 2.5 μg/ACT IN AERS	Anticholinergics
130663	Spiriva Respimat IN	Anticholinergics
91222	Tiotropium bromide monohydrate	Anticholinergics
133714	Tiotropium bromide monohydrate 1.25 μg/ACT IN AERS	Anticholinergics
43672	Tiotropium bromide monohydrate 18 μg IN CAPS	Anticholinergics
130394	Tiotropium bromide monohydrate 2.5 μg/ACT IN AERS	Anticholinergics
81562	Tiotropium bromide monohydrate IN	Anticholinergics
120704	Tudorza Pressair 400 μg/ACT IN AEPB	Anticholinergics
120880	Tudorza Pressair IN	Anticholinergics
131119	Umeclidinium bromide	Anticholinergics
130705	Umeclidinium bromide 62.5 μg/INH IN AEPB	Anticholinergics
131098	Umeclidinium bromide IN	Anticholinergics
91245	Ipratropium-albuterol	Anticholinergics
97202	Ipratropium-albuterol 0.5-2.5 (3) mg/3 mL IN SOLN	Anticholinergics
16477	Ipratropium-albuterol 18-103 μg/ACT IN AERO	Anticholinergics
119838	Ipratropium-albuterol 20-100 μg/ACT IN AERS	Anticholinergics
98087	Ipratropium-albuterol IN	Anticholinergics

AERO, Aerosolized; *AERS*, aerosolized; *CHEMO*, chemotherapy; *CONC*, concentrate; *CUST*, custom; *D5W*, dextrose 5% in water; *Dex*, dexamethasone; *ELIX*, elixer; *ER*, extended-release; *HCL*, hydrochloride; *HFA*, hydrofluoroalkane; *ICS*, inhaled corticosteroid; *IJ*, injection; *IN*, inhallation; *INH*, inhallation; *INHAL*, inhallation; *INJ*, injection; *INJECT*, injection; *IV*, intravenous; *LABA*, long-acting beta agonist; *LIDO*, lidocaine; *NEB*, nebulizer; *NEBU*, nebulizer; *NSS*, normal saline solution; *OR*, oral; *PAK*, pack; *PHOS*, phosphate; *PKT*, packet; *po*, *per os* (by mouth); *POWD*, powder; *SC*, subcutaneous; *SOD*, sodium; *SOL*, solution; *SOLN*, solution; *SUSP*, suspension; *SWFI*, sterile water for injection; *SYRP*, syrup; *TABS*, tablets; *TBEC*, enteric coated tablet; *TBPK*, tablet pack.

TABLE E2. Demographic characteristics of asthma prescription encounters

	Prescription cohort (n)	
Characteristic	**All medicines (1624)**	**Steroids (402)**
Sex, n (%)		
Male	917 (56)	213 (53)
Female	708 (44)	189 (47)
Race, n (%)		
White	664 (41)	74 (18)
Black	666 (41)	280 (70)
Asian/Pacific Islander	36 (2)	6 (1)
Other	252 (16)	42 (10)
Unknown	7 (0)	0 (0)
Ethnicity, n (%)		
Non-Hispanic/Latino	1434 (88)	372 (93)
Hispanic/Latino	180 (11)	30 (7)
Unknown	11 (1)	0 (0)
Birth year, n (%)		
Before 2000	11 (1)	1 (0)
2000-2004	208 (13)	62 (15)
2005-2009	392 (24)	85 (21)
2010-2014	533 (33)	131 (33)
2015 or later	481 (30)	123 (31)
Payer type, n (%)		
Non-Medicaid	912 (56)	148 (37)
Medicaid	713 (44)	254 (63)

TABLE E3. Controlled interrupted time series regression analysis results for 4 criteria air pollutants

	$PM_{2.5}$		Ozone		PM_{10}	NO_2
Variables	**AirNow**	**AirData**	**AirNow**	**AirData**	**AirData**	**AirData**
Days (*P* value)	−0.03 (.064)	−0.05 (.002)	0.26 (<.0001)	0.27 (<.0001)	−0.044 (.23)	−0.07 (.04)
Year 2020 (*P* value)	−3.51 (.0005)	−3.58 (.0002)	2.18 (.25)	1.16 (.54)	−5.40 (.004)	−0.77 (.66)
Covid_restrictions (*P* value)	−5.25 (.009)	−4.56 (.019)	16.08 (<.0001)	12.90 (.0007)	−0.52 (.88)	−0.33 (.92)
Days × Year 2020 (*P* value)	0.0009 (.97)	0.02 (.41)	−0.03 (.52)	−0.04 (.42)	−0.005 (.92)	−0.01 (.70)
Days × Covid_restrictions (*P* value)	0.045 (.10)	0.05 (.04)	−0.24 (<.0001)	−0.2 (<.0001)	0.006 (.90)	−0.001 (.98)
Year 2020 × Covid_restrictions (*P* value)	2.24 (.42)	1.56 (.56)	−6.56 (.21)	−3.48 (.51)	−7.57 (.15)	−5.5 (.26)
Days × Year 2020 × Covid_restrictions (*P* value)	−0.005 (.88)	−0.01 (.66)	0.09 (.2)	0.05 (.44)	0.08 (.27)	0.05 (.41)

Outcome was levels of each pollutant. Independent variables included days, referring to the 120 d between January 17 and May 17; year 2020, indicating whether it was the year 2020 or historical time period; covid_restrictions, indicating whether the measure was from before or after March 17. Each column corresponds to 1 model with indicated outcome variable and source of historical measures (AirNow or AirData). Terms in the model are indicated in each row. Values are coefficient estimate (*P* value).