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ORIGINAL RESEARCH

Pediatrics

The impact of public health interventions on critical illness in the pediatric emergency department during the SARS-CoV-2 pandemic

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Abstract

Study objective: The impact of public health interventions during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic on critical illness in children has not been studied. We seek to determine the impact of SARS-CoV-2 related public health interventions on emergency healthcare utilization and frequency of critical illness in children.

Methods: This was an interrupted time series analysis conducted at a single tertiary pediatric emergency department (PED). All patients evaluated by a provider from December 31 through May 14 of 6 consecutive years (2015-2020) were included. Total patient visits (ED and urgent care), shock trauma suite (STS) volume, and measures of critical illness were compared between the SARS-CoV-2 period (December 31, 2019 to May 14, 2020) and the same period for the previous 5 years combined. A segmented regression model was used to explore differences in the 3 outcomes between the study and control period.

Results: Total visits, STS volume, and volume of critical illness were all significantly lower during the SARS-CoV-2 period. During the height of public health interventions, per day there were 151 fewer total visits and 7 fewer patients evaluated in the STS. The odds of having a 24-hour period without a single critical patient were >5 times higher. Trends appeared to start before the statewide shelter-in-place order and lasted for at least 8 weeks.

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Conclusions: In a metropolitan area without significant SARS-CoV-2 seeding, the pandemic was associated with a marked reduction in PED visits for critical pediatric illness.

1 | INTRODUCTION

1.1 | Background

On March 11, 2020, the World Health Organization declared the outbreak of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) a pandemic.[1] As of July 17, SARS-CoV-2 has infected >14 million worldwide and caused at least 600,000 deaths,[2] with significant burden placed on healthcare systems in communities with substantial viral seeding.[3-5]

Without a vaccine or definitive treatment, non-pharmacologic public health interventions are the foundation for lowering viral transmission rates and slowing disease spread.[6] In previous pandemics, public health interventions have been credited with slower spread and fewer deaths.[7,8] Early studies examining the impact of these interventions during the SARS-CoV-2 outbreak suggest that they result in lower viral transmission rates and improved disease control.[9-12]

1.2 | Importance

Recently published studies have shown marked reductions in both adult and pediatric patient volumes during the SARS-CoV-2 pandemic.[13-19] In children, patient volume decreases have been seen in multiple settings of health care, including outpatient and emergency department settings.[13-18] Additionally, multiple studies have evaluated changes in specific illness and injury patterns in children presenting for care during the pandemic.[14,17,18] Despite the growing body of evidence for a reduction of ED visits in children,[13,15-17,20,21] no published study has focused on changes in critical illness presenting to the pediatric emergency department (PED). Moreover, the impact of public health interventions on the timing of changes in critical illness and injury patterns in children has not been studied. When compared to non-critically ill or injured patients, critically ill and injured patients are more likely to suffer morbidity and mortality and require more departmental resources during their care. Understanding critical illness presentation patterns during the SARS-CoV-2 pandemic can help guide planning and resource allocation during both the ongoing pandemic as well as future pandemics.

1.3 | Goals of this investigation

The SARS-CoV-2 pandemic offers a unique opportunity to study the effects of public health interventions, both on the disease of interest and more broadly. This study addresses the literature gap through an interrupted time-series analysis of ED and urgent care visits to a regional pediatric referral center. The study objective is to describe the impact of public health interventions during the SARS-CoV-2 pandemic on critical illness presenting to the PED.

2 | METHODS

2.1 | Study design and setting

This was a retrospective, observational study of patient visits to the ED and urgent care at Cincinnati Children's Hospital Medical Center. The ED is the major regional pediatric emergency care provider and the only pediatric referral center. The ED and associated urgent care have ≈100,000 combined patient visits per year. The catchment area has over 2 million people, drawing from 8 counties in 3 states.

Critically ill or injured patients are evaluated in the ED's shock trauma suite (STS). Pediatric emergency nurses triage patients to the STS using a combination of the Emergency Severity Index (version 4), specific trauma criteria, and nursing discretion.[22] Board-certified/eligible pediatric emergency physicians lead designated medical and trauma teams.

The study protocol was approved by our institutional review board. The current report is written to be consistent with published guidelines for reporting the results of observational studies (STrengthening the Reporting of OBservational studies in Epidemiology).[23]

2.2 | Selection of participants

All patients who presented to the ED or urgent care from December 31 through May 14 across 6 consecutive years (2015-2020) were eligible for inclusion. Patients who left without being seen by a physician or nurse practitioner were excluded. Eligible visits were identified using our institution's electronic health record (EHR).

2.3 | Measurements

Data were collected from the EHR using 2 approaches. We used a single EHR query to collect data on total patient visits. We collected STS-specific data, including measures of critical illness, from an existing internal database of all STS encounters. A pediatric emergency nurse has maintained the STS database since 2015, using automated EHR daily reports and supplemented by manual EHR review. The STS database is used for quality assurance and peer review activities, and we have a track record of successful research using this approach.

2.4 | Outcomes

The main outcomes were (1) total patient visits, (2) STS volume, and (3) critical illness volume. All 3 outcomes were measured by total number of patient visits per day. *Total patient visits* consisted of ED and urgent care visits combined. *STS volume* consisted of patients who triggered a medical or trauma team activation in the STS. We specified medical or trauma team activation as a criterion for inclusion in STS volume as our STS is occasionally used to treat non-critically ill patients who require time-sensitive interventions. *Critical illness* was defined as a patient evaluated in the STS who triggered a medical or trauma team activation and met at least 1 of 3 criteria: (1) admitted to an intensive care unit (ICU) or operating room, (2) cardiopulmonary resuscitation (CPR) performed in the STS, or (3) had a critical procedure performed in the STS. Critical procedures included tracheal intubation, thoracostomy tube placement, intraosseous (IO) catheterization, and central venous catheter or arterial line placement. STS volume is a subset of total patient visits, and critical illness volume is a subset of both.

2.5 | Analysis

We first tabulated all data and generated standard descriptive statistics, including for each outcome. We report medians and interquartile ranges for continuous variables and number of patients (%) for categorical variables. The main analysis compared the 3 study outcomes between 2 patient groups: December 31, 2019 to May 14, 2020 (SARS-CoV-2 pandemic, main exposure) and the same dates for the previous 5 years combined (control group). Between these 2 groups, we specifically examined differences across 5 public health-related time periods: (1) period 1 was from the first reported SARS-CoV-2 case in Wuhan, China on December 31, 2019 to January 18, 2020; (2) period 2 was from the first reported case in the United States on January 19, 2020 to March 8, 2020; (3) period 3 was from the first reported case in Ohio on March 9, 2020 to March 15, 2020; (4) period 4 was from the start of local public school closures on March 16, 2020 to April 30, 2020; and (5) period 5 was from the end of local shelter-in-place orders on May 1, 2020 to May 14, 2020.

We selected the 5 time periods a priori, based on the specific dates' theoretical public health relevance (to patient volumes).[16,24] Period 4 (school closures to the end of statewide shelter-in-place order) included the initiation of other public health interventions, including the start of the statewide shelter-in-place order. The primary catchment area for the study ED is southwestern Ohio, northern Kentucky, and southeastern Indiana. The first reported cases in Kentucky and Indiana were on March 6, 2020, and both states began mandated public health interventions on March 16, 2020. As the dates for the 3 states were similar and the majority of patient visits are from Ohio, we used relevant dates for Ohio to define the time periods.

The Bottom Line

Many US communities enacted public health isolation policies during the coronavirus disease 2019 (COVID-19) pandemic, with unclear impacts on local health systems. In this analysis of data from Cincinnati Children's Hospital during December 31, 2019–May 14, 2020, public health interventions to stem COVID-19 resulted in dramatic reductions in total pediatric ED visits, including a 5-fold decrease in critically ill pediatric patients. These findings provide valuable perspectives to inform regional pandemic preparedness.

For all 3 outcomes, we conducted robust interrupted time series analyses with segmented regression,[25,26] to assess differences between the pandemic and control groups. We used scatter plots and smooth curves of the time series to examine potential trends and dispersion. We assumed the intervention effects on the primary outcome would be non-linear and eventually reach a plateau. An exponential decay model was then built to evaluate decay rates in each outcome after the initiation of local public health interventions.

For total patient visits and STS volume, we used linear mixed modeling. We calculated the differences in mean total patient visits and STS volume (daily), with corresponding 95% confidence interval (CI), for each of the 5 periods. We included terms for time period, intervention group, and period-by-group interaction as fixed effects. For the random effect, we used a first-order auto-regression correlation structure to account for autocorrelation by inclusion seasonality and adjusted year-to-year variations during the control period for deterministic intervention effectiveness. Other covariance structures such as smoothing spline and moving average covariance matrix were compared by Auto Correlation Function plot. The final model was selected based on Akaike information criterion.

For critical illness volume, we conducted zero-inflated Poisson mixed effects modeling to assess differences in daily volume between the pandemic and control groups.[27] As the frequency of zero daily critical illness visits was common, we calculated the odds of zero daily critical illness visits in the pandemic versus the control group for each of the 5 periods. *P* values <0.05 were considered statistically significant. All analyses were performed with SAS Version 9.4 (SAS Institute, Cary, NC, USA).

3 | RESULTS

3.1 | Characteristics of study subjects

From December 31, 2019 through May 14, 2020 (pandemic group), the ED and urgent care had a total of 28,534 patient visits. Of these, 951 (3.3%) were evaluated in the STS for a medical or trauma team activation. For the same time period in 2015-2019 there were 181,824 total

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TABLE 1 Characteristics for patients visits

	Study period	Control period
Total	28,534	181,824
Age (years), median (IQR)	6.1 (1.9-13.0)	6.0 (1.8-12.7)
Sex, No. (%)		
Female	14,518 (50.9)	90,616 (49.8)
Race, No. (%)		
White	14,364 (50.3)	87,089 (47.9)
Black	12,060 (42.3)	81,703 (44.9)
Asian	451 (1.6)	2391 (1.3)
Other	1056 (3.7)	6661 (3.4)
Unknown	603 (2.1)	3980 (2.2)
Ethnicity, No. (%)		
Non-Hispanic	26,636 (93.4)	170,714 (93.9)
Hispanic	1673 (5.9)	9763 (5.4)
Insurance status, No. (%)		
Medicaid	16,948 (59.4)	116,519 (64.1)
Private/Employer based	9389 (32.9)	56,124 (30.9)
Self-pay	2044 (7.2)	7962 (4.4)
Medicare	62 (0.2)	334 (0.2)
Other	91 (0.3)	880 (0.5)
STS Team Activation, No. (%)		
Medical	625 (65.7)	4513 (62.2)
Trauma	326 (34.3)	2741 (37.8)

IQR, interquartile range; No, number; STS, shock trauma suite.
Data shown for total patient visits to the emergency department and urgent care of a pediatric institution from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Median (IQR) or n (%) shown.

ED/urgent care visits and 7254 medical or trauma team STS evaluations (4.0%)—an average of 36,365 ED/urgent care visits and 1451 STS evaluations.

Patient characteristics for the 2 study groups are provided in Table 1. Patient age and sex were similar between the pandemic and control groups. In both groups, approximately two thirds of STS evaluations were medical (non-trauma evaluations).

3.2 | Main results

During the pandemic, total patient visits were unchanged in periods 1 and 2. Total visits began decreasing in period 3 (before the official shelter-in-place order), reached a nadir in period 4, and continued at similar levels for at least 8 weeks (Figure 1, Table 2). During the height of local public health interventions, there were 151 fewer total patient visits per day than in the previous 5 years. Following the initiation of local public health interventions, total patient volume had a daily decay rate of −19.4% (95% CI −22.6%, −14.1%) (Figure 2).

Daily STS volume during the pandemic generally mirrored the decrease in total patient visits (Figure 3, Table 2). During the height of local public health interventions, there were 7 fewer patients evaluated in the STS per day than in the previous 5 years. Following the initiation of local public health interventions, STS volume had a daily decay rate of −9.9% (95% CI −18.9%, −0.85%) (Figure 4).

Critical illness volumes during the pandemic were similar in periods 1-3 (Figure 5). During period 4, the first 6 weeks after public school closings and the shelter-in-place order, the odds of having a 24-hour period without a single critically ill patient were 5.5 higher during the pandemic (95% CI 2.6, 11.7; Table 2). During period 5, critical illness volumes were similar between the pandemic and control groups.

4 | LIMITATIONS

Our study should be interpreted in light of 2 main limitations. First, this was a single-center study, limiting generalizability. Ohio's state-mandated shelter-in-place order occurred relatively early in the US outbreak, rates of SARS-CoV-2 infection in Ohio have been initially lower compared to other states of similar population,[2] and our metropolitan area had no substantial seeding of SARS-CoV-2 before widespread public health interventions began. As the observed decreases in patient volumes were similar to published studies and the vast majority of patients with critical pediatric illness in our region are cared for in our ED, we believe our results are likely representative of metropolitan areas with similar pandemic dynamics. Given the similarity of the magnitude of the decrease in total visits between our study and recently published studies, our results for total ED visits may be even more broadly generalizable. Our data on critical illness are unique in the published literature; thus the generalizability of these data are less clear, especially given our lack of understanding of the factors driving this apparent decrease.

A second important limitation is that we measured visits and not the actual incidence of illness or injury. We believe that a large percentage of the drop in *total* visits was for conditions that might be addressed by phone or telehealth visits. Our institution, like many others throughout the country, put an increased emphasis on telehealth visits during the mandated shelter-in-place order. As noted, however, we believe caregivers seeking alternatives to ED care does not explain all, or even most, of the drop in STS volume; we believe the drop in patients with critical illness visits is not explainable by an increase in alternative visits.

5 | DISCUSSION

The main objectives of non-pharmacologic public health interventions are to decrease transmission within an affected community and to decrease spread to unaffected communities. Social distancing and related interventions are intended to decrease the intensity of established disease clusters and prevent new clusters from forming. The

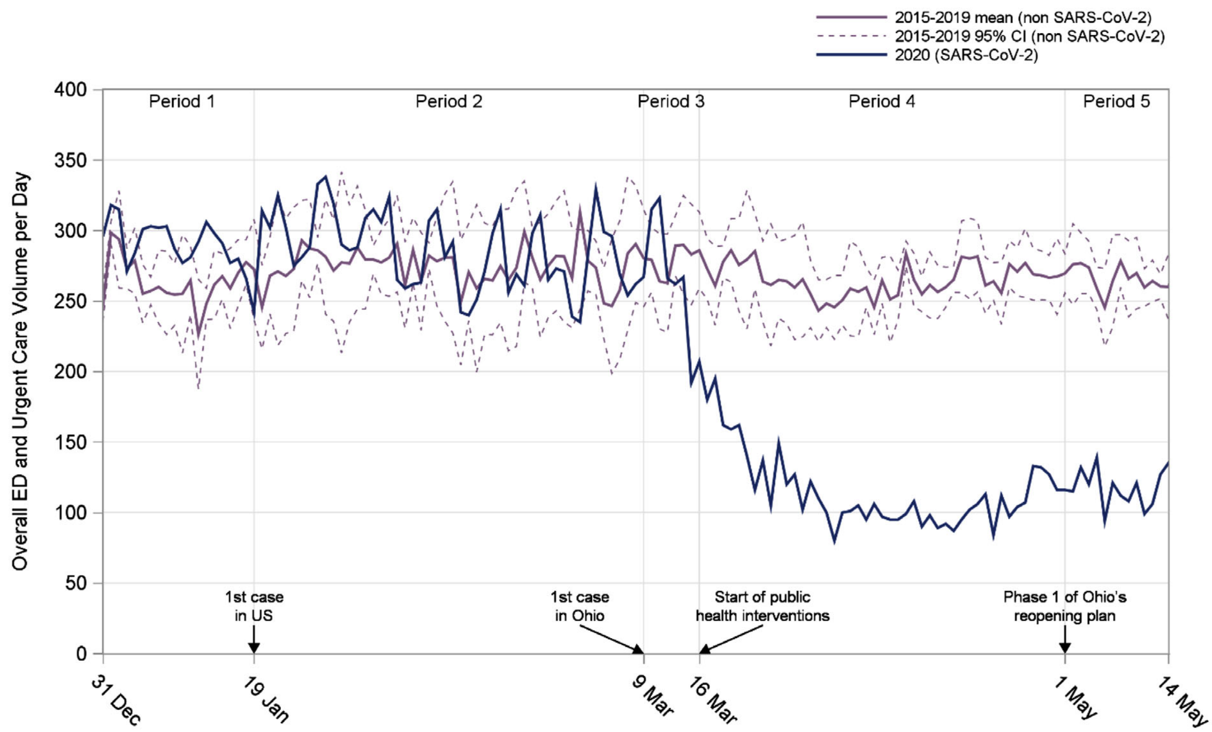

FIGURE 1 Total patient visits during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. Daily patient visits to the emergency department and urgent care of a pediatric institution from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions

TABLE 2 Results of interrupted time series analysis

Outcomes	Period 1 December 31–January 18	2 January 19–March 8	3 March 9–March 15	4 March 16 –April 30	5 May 1–May 14
Patient visits					
Difference from control (95% CI)	26.0 (−8.5, 60.5)	8.3 (−24.2, 40.7)	−10.6 (−50.3, 29.0)	−151.4 (−183.9, −118.8)	−151.3 (−186.7, −116.0)
P	0.14	0.62	0.60	<0.001	<0.001
STS volume					
Difference from control (95% CI)	0.3 (−1.6, 2.1)	−1.6 (−2.9, −0.3)	−2.4 (−5.4, 0.5)	−7.0 (−8.4, −5.7)	−6.7 (−8.8, −4.6)
P	0.79	0.02	0.11	<0.001	<0.001
Critical illness					
Odds of zero daily visits					
Odds ratio (95% CI)	1.3 (0.3, 5.1)	2.5 (1.0, 6.5)	1.0 (0.1, 10.2)	5.5 (2.6, 11.7)	2.9 (0.8, 11.0)
P	0.71	0.06	>0.99	<0.001	0.12

CI, confidence interval; STS, shock trauma suite.

Data shown for 3 study outcomes: total visits (emergency department and urgent care combined), STS volume, and critical illness volume. All 3 outcomes are reported as daily volumes. *Difference* represents the value in the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic group (December 31, 2019 to May 14, 2020) compared with the same period for the previous 5 years.

Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions.

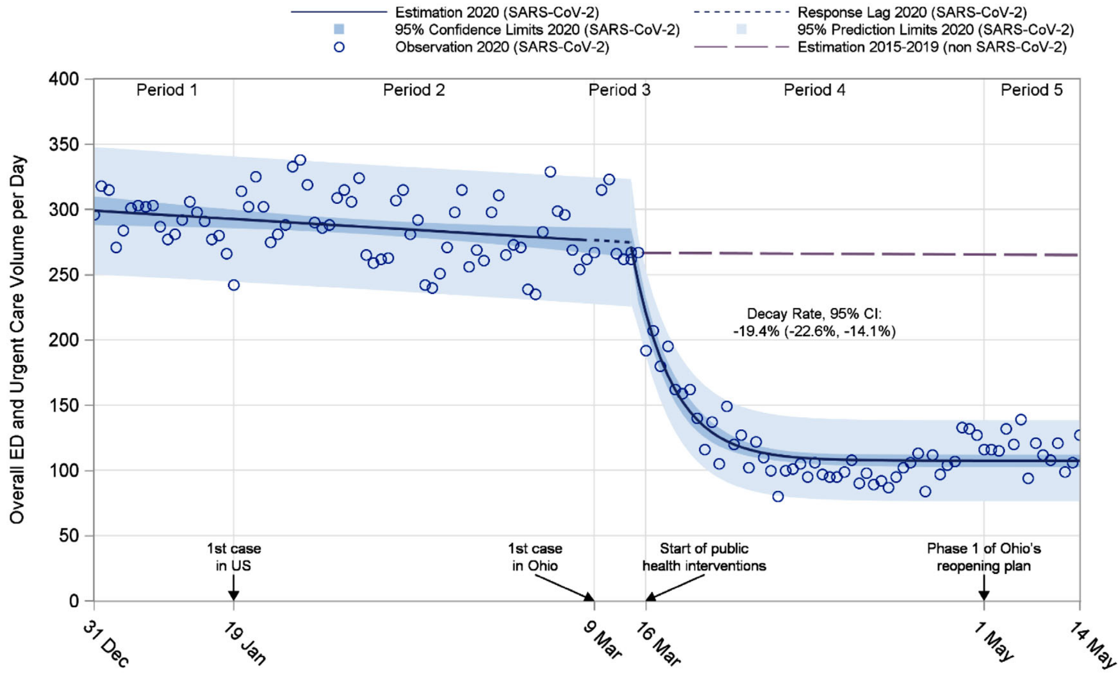

FIGURE 2 Total patient visits trend during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic estimated by segmented regression. Total patient visits to the emergency department and urgent care of a pediatric institution from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions

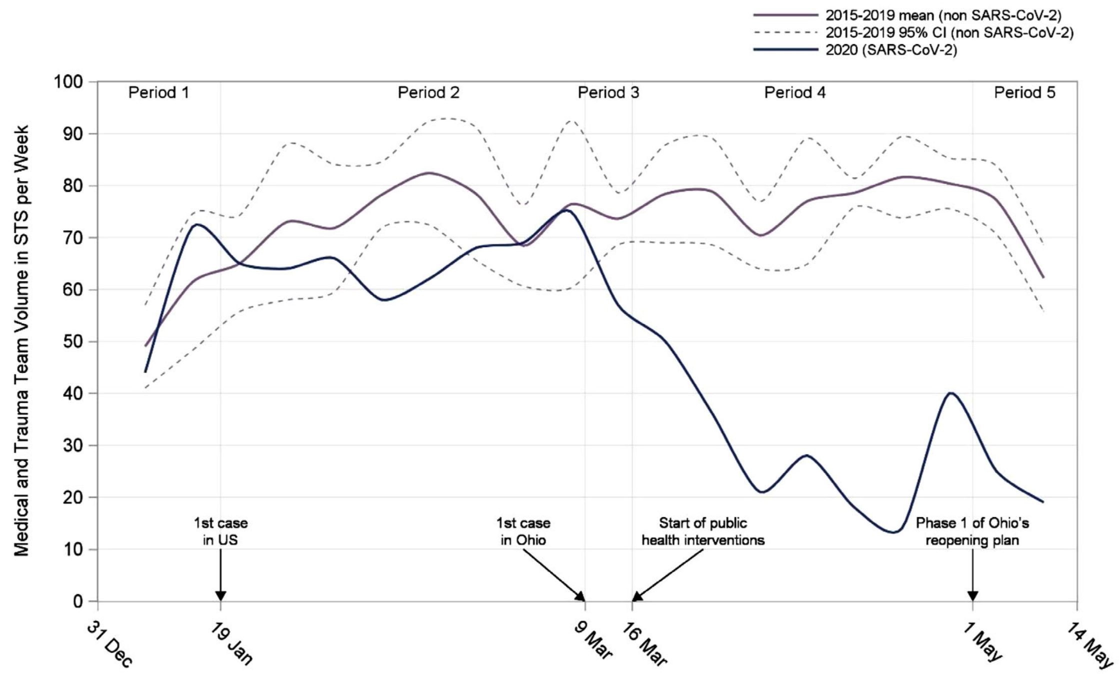

FIGURE 3 Shock trauma suite (STS) volume during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. Weekly shock trauma suite volume in a pediatric emergency department from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Weekly volumes used to limit variability and improve visualization. Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions

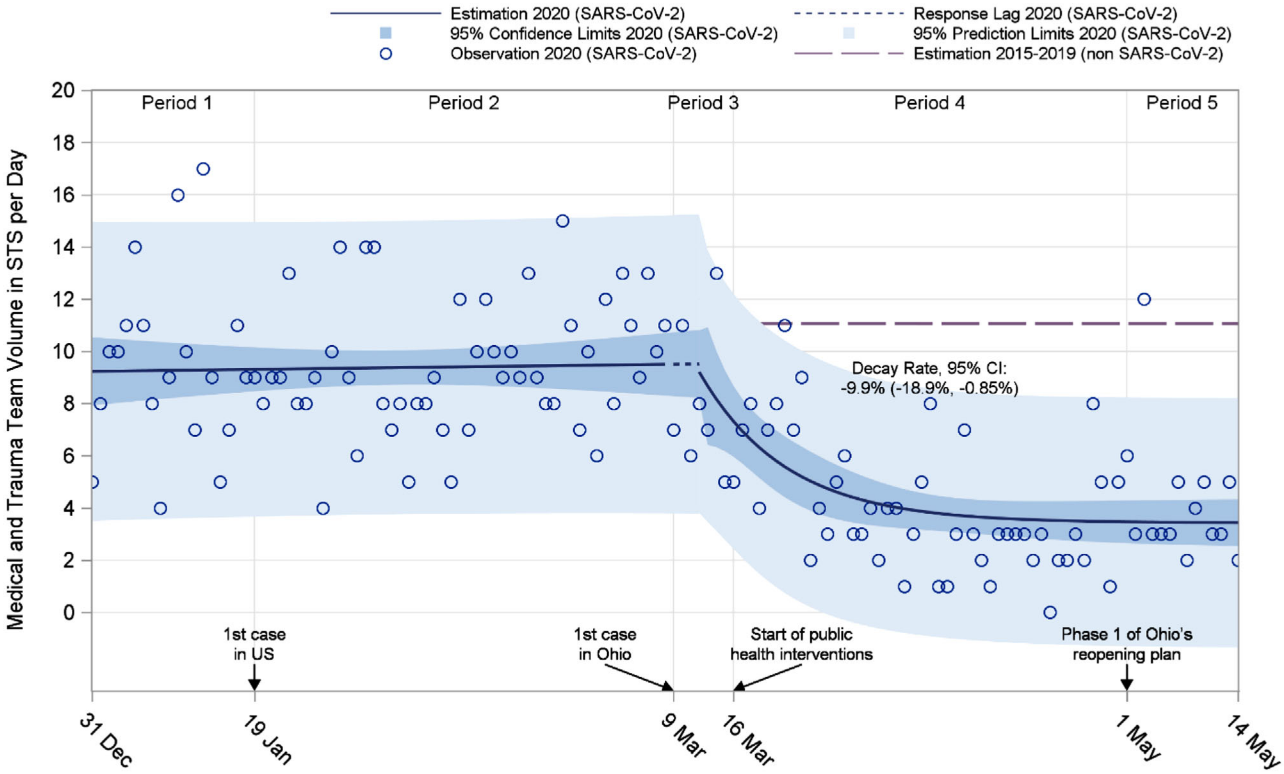

FIGURE 4 Shock trauma suite (STS) volume trend during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic estimated by segmented regression. Shock trauma suite volume in a pediatric emergency department from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions

published literature suggests public health interventions are effective, when applied early and in a multifaceted approach, including for SARS-CoV-2.[9-12,28-30] However, the rare nature of pandemics on the scale of SARS-CoV-2 limits our ability to study the impact of public health interventions outside of the target disease including for non-SARS-CoV-2 critical illness.

Our findings of a significant drop in critical illness volume is relatively unique in the published literature. The decreases in total visits, as well as STS and critical illness volumes, were concurrent, suggesting that the changes were related and that public health interventions or other factors affected all 3 outcomes in a similar way. The key question to interpreting the change in volumes is whether patients with critical illnesses stayed home more often during the pandemic/sought care elsewhere or critical illnesses were truly less common. We believe the former is highly unlikely, as disease processes that ultimately require critical or intensive care typically do not resolve without treatment. Moreover, we are the only provider of critical care to children in our region, and we used measures of both STS volume and critical illness to mitigate the impact of triage dynamics unique to our ED and operational changes on the outcomes of interest.

We postulate the decrease in critical illness visits is primarily due to a combination of real decrease in non-SARS-CoV-2 infectious diseases, including those that trigger chronic illnesses, and a decrease in serious traumatic injuries. Infectious diseases can directly (ie, septic shock, respiratory failure) or indirectly (ie, status epilepticus, severe asthma, diabetic ketoacidosis) lead to critical illness. As the only regional referral center for children, our patient population includes a high percentage of patients with chronic or complex medical problems, and patients with chronic illnesses are at higher risk of critical illness and complications from infectious diseases. More vulnerable members of our patient population, especially children with chronic or complex medical problems, may have been uniquely protected by the public health interventions intended to prevent the spread of SARS-CoV-2. Multiple recently published studies have found evidence of public health interventions decreasing the spread of non-SARS-CoV-2 infectious diseases.[14,17] Additionally, during local public health interventions there was a 60% reduction in reported motor vehicle accidents in the Ohio counties of our catchment area when compared to the same dates in the control years.[31] Fewer motor vehicle accidents, combined with a probable reduction in both organized and unorganized recreational activities, likely contributed to decreased rates of critical traumatic injuries.[32]

We did not collect data on diagnostic category or chief complaint, so we cannot state definitively which specific forms of critical illness were

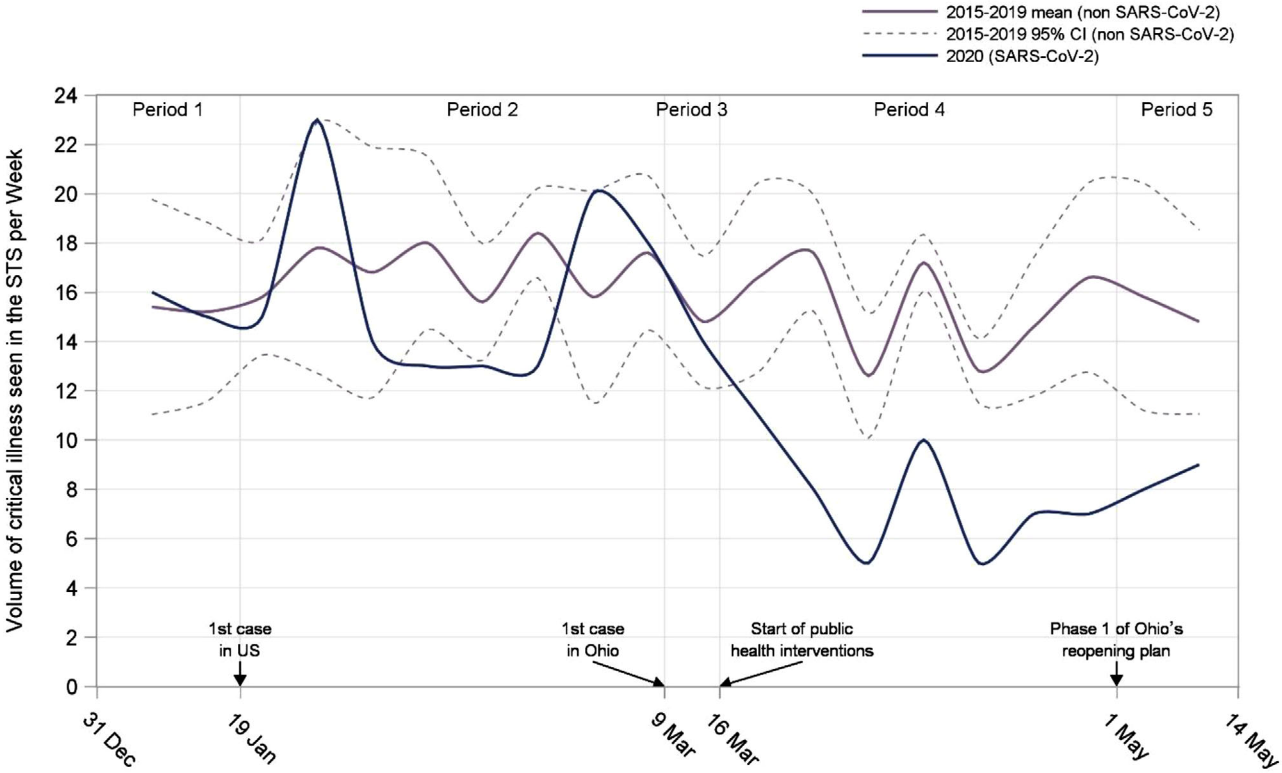

FIGURE 5 Critical illness volume during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. Weekly critical illness volume in a pediatric emergency department from December 31, 2019 through May 14, 2020 during the SARS-CoV-2 pandemic (study group) and the same period for the previous 5 years. Weekly volumes used to limit variability and improve visualization. Period 1 (December 31 to January 18): time after first case reported in Wuhan, China. Period 2 (January 19 to March 8): time after first case reported in the United States. Period 3 (March 9 to March 15): time after first case reported in Ohio. Period 4 (March 16 to April 30): time of local mandated public health interventions. Period 5 (May 1 to May 14): initiation of relaxation of mandated public health interventions. STS, shock trauma suite

less common. As the monthly volumes of critical illness are relatively low, even for a regional center with a catchment area in the millions, detecting changes over time in specific disease processes is very difficult. To detect a change in the presentation of specific forms of critical illnesses or injury, a multicenter study is needed, one employing a validated approach to diagnostic categorization.

The *timing* of the decrease in patient volumes is notable, as the start of the outbreak in China and the first reported case in the United States were not associated with a change in patient volumes. Patient volumes began dropping after the first Ohio case was reported March 9th, but before the local public health interventions began on March 16. The official announcement of public school closures occurred on March 12, 2020, which potentially affected pediatric volume more than general or adult ED volumes. This finding differs from the only comparable study, from Toronto during the 2003 SARS-CoV-1 outbreak, in which decreases in patient volumes were not seen until after infection control measures were implemented.[33] Our findings suggest that factors other than public awareness and official orders triggered the initial decrease in healthcare utilization. We speculate that these factors may include the intensity or specific type of media coverage, high morbidity and mortality rates in early hot spots, and caregivers' perceptions about the level of personal risk of disease exposure.[15,34]

Our findings provide additional epidemiologic evidence of how nonpharmacologic public health interventions likely affect the typical pattern of infectious diseases and traumatic injuries in a community. It will be vital to follow healthcare utilization rates and critical illness volumes during and after public health interventions are relaxed. In a state still experiencing significant numbers of new cases daily, the impact of less stringent public health interventions remains to be seen.[2]

In summary, public health interventions in a metropolitan area without significant community seeding of SARS-CoV-2 led to profound and persistent decreases in PED utilization, including for critical illness and injury. The latter change likely represents a decreased incidence of more serious conditions, possibly from an indirect effect of social distancing and shelter-in-place orders on the typical pattern of non-SARS-CoV-2 infectious diseases and traumatic injuries in children. The current pandemic presents a unique opportunity for epidemiologic investigations such as ours that can influence planning and resource allocation in future pandemics and inform future epidemiologic studies.

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CONFLICTS OF INTEREST

The authors have no potential conflicts of interest to disclose.

AUTHORS CONTRIBUTIONS

Preston Dean, Benjamin Kerrey, Yin Zhang, Mary Frey, Ashish Shah, Katherine Edmunds, Stephanie Boyd, Hamilton Schwartz, Theresa Frey, Erika Stalets, Joshua Schaffzin, Adam A. Vukovic, and Tonya Masur conceived and designed the study. Preston Dean and Benjamin Kerrey supervised data collection. Yin Zhang provided statistical advice and analyzed the data. Preston Dean and Benjamin Kerrey drafted the manuscript, and all authors contributed substantially to its revision. Preston Dean takes full responsibility for the paper as a whole.

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