School Closures in the United States and Severe Respiratory Illnesses in Children: A Normalized Nationwide Sample

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OBJECTIVES: To determine the association between nationwide school closures and prevalence of common admission diagnoses in the pediatric critical care unit.

DESIGN: Retrospective cohort study.

SETTING: National database evaluation using the Virtual Pediatric Systems LLC database.

PATIENTS: All patients admitted to the PICU in 81 contributing hospitals in the United States.

MEASUREMENTS AND MAIN RESULTS: Diagnosis categories were determined for all 110,418 patients admitted during the 20-week study period in each year (2018, 2019, and 2020). Admission data were normalized relative to statewide school closure dates for each patient using geographic data. The "before school closure" epoch was defined as 8 weeks prior to school closure, and the "after school closure" epoch was defined as 12 weeks following school closure. For each diagnosis, admission ratios for each study day were calculated by dividing 2020 admissions by 2018–2019 admissions. The 10 most common diagnosis categories were examined. Significant changes in admission ratios were identified for bronchiolitis, pneumonia, and asthma. These changes occurred at 2, 8, and 35 days following school closure, respectively. PICU admissions decreased by 82% for bronchiolitis, 76% for pneumonia, and 76% for asthma. Nonrespiratory diseases such as diabetic ketoacidosis, status epilepticus, traumatic injury, and poisoning/ingestion did not show significant changes following school closure.

CONCLUSIONS: School closures are associated with a dramatic reduction in the prevalence of severe respiratory disease requiring PICU admission. School closure may be an effective tool to mitigate future pandemics but should be balanced with potential academic, economic, mental health, and social consequences.

KEY WORDS: COVID-19; epidemiology; informatics; pediatric critical care; pediatrics; public health

In the first wave of the COVID-19 pandemic, the public health response in the United States varied by state (1). Although public health protective measures such as mandated masking, social distancing, and in-person school closure varied in degree and timing during the first few weeks of the pandemic, in-person school was closed in all states by April 2020 (2).

Given that these school closures comprised one of the largest public health measures in history, we sought to investigate the relationship between the epidemiology of severe illnesses in children and the timing of these school closures. The primary objective in mandating school closures was to slow the spread of a deadly new contagion. In addition to limiting the spread of COVID-19, other severe pediatric respiratory diseases were also likely prevented from spreading. However, significant direct and indirect negative consequences of

DOI: 10.1097/PCC.0000000000002967

school closure on children include academic learning loss, decreased access to nutritional and other support programs, and changes to daily routines and activities (3–11). Furthermore, school closures limit access to school nurses who provide direct care to patients with chronic conditions by administering medications or executing emergency care plans (12). This may, in turn, exacerbate underlying chronic conditions.

We hypothesized that school closure would be associated with a decreased prevalence of severe respiratory disease in children requiring admission to the PICU. Additionally, we aimed to develop a methodology to assess the effects of a widespread public health intervention with different onset times. A secondary aim was to determine the association between school closures and the prevalence of noninfectious diseases often managed with maintenance medications.

MATERIALS AND METHODS

We conducted a retrospective, observational study using a cohort of patients identified using the Virtual Pediatric Systems (VPS, LLC) database (Virtual Pediatric Systems, LLC, Los Angeles, CA). The VPS is a clinical database dedicated to standardized data sharing among PICUs and is used to track outcomes, measure quality, and conduct research. VPS neither endorsed nor restricted our interpretation of these data. Our aim was to compare patient data before school closure to after school closure. This study was reviewed by the Institutional Review Board (IRB) of Connecticut Children's Medical Center, IRB number 20-080, and was determined to be nonhuman subject research, and consent was waived.

Patient-level data were obtained for all children less than 18 years old admitted to any of 81 participating PICUs in the United States and adjusted for the date of the school closure for the state in which the PICU is located as follows. Dates of school closure were obtained from previously published research (2) and cross-checked with state department of education websites. In 2020, date of school closure was defined as day 0, and before and after dates were defined using relative integers (e.g., +1 from closure and –1 from closure) from 8 weeks before that school closure date to 12 weeks after that date. For the 2018 and 2019 cohorts, day 0 was defined as 1 and 2 years (respectively) before day 0 in 2020, and admission data were collected from 8 weeks before that date (before school closure) to 12 weeks after that date (after school closure). Patient characteristics and outcomes are presented descriptively with frequency, percentage, and median with interquartile range (IQR). PICU length of stay is calculated in VPS using the difference between physical discharge date and time and admission date and time, and is measured in hours and minutes. Characteristics were compared before and after school closure using the chi-square or Fisher exact test for categorical data and the Mann-Whitney *U* test for continuous data. Data were analyzed using the SAS software (2016; SAS Institute, Cary, NC).

Primary diagnoses were examined and categorized into diagnostic categories using methods previously described (13). The 10 most common diagnosis categories for the combined cohort of patients from all included years were included in this analysis. For these most common disease categories (**Table 1**), ratios were calculated by using the number of admissions per day for that disease in 2020 over the mean number of admissions per day for that disease in 2018–2019.

Modified statistical process control charts (14) were used to determine at which school closure date the ratio of admissions went out of process. The first 10 days of the study period (i.e., day –56 to day –47) were used to determine a baseline mean ratio. Next, we noted the first set of 7 consecutive days when the ratio was consistently above or below two standard deviations of the baseline mean, thus establishing a cut point for a new baseline. The new baseline ratio was calculated as the mean of the subsequent seven consecutive points. This process was repeated to determine each school closure day when the ratio significantly changed from the previous process. To determine statistical significance of each cut point, the Chow test (15) was used to compare the slope before versus after cut point and was evaluated at the 0.05 significance level.

RESULTS

In the entire dataset, there were a total of 110,418 patients, with 46% (n = 50,783) admitted prior to school closure and 54% (n = 59,635) admitted after school closure. Patient characteristics are described in **Table 2**. There was a significant difference in the age of patients before versus after school closure, with a lower percentage of younger children and a higher percentage

TABLE 1.
Ratios of Children Admitted per Day in the Most Common Diagnosis Categories

Diagnosis	Ratio (Average Admits per Day 2020/ Average Admits per Day 2018 and 2019) Before School Closure[a] (56 d)	After School Closure[b] (85 d)	Total Admits
Asthma	1.04	0.19	6,588
Brain-skull trauma	0.96	0.88	3,936
Bronchiolitis	0.97	0.22	14,129
Cardiac surgery	0.90	0.72	4,157
Diabetes mellitus	0.95	1.17	5,526
Pneumonia	1.33	0.39	6,503
Poisoning/ingestion	1.19	1.07	4,668
Respiratory failure/arrest (including acute respiratory distress syndrome)	1.03	0.53	3,046
Seizures/epilepsy	0.91	0.65	6,204
Sepsis	1.12	0.84	3,468

[a]Ratio of average PICU admissions per day for 56 d before school closure.
[b]Ratio of average PICU admissions per day for 85 d after school closure.
Table characterizes data used for analysis.

of adolescent children in the after school closure subgroup. A significant difference was also found in PICU length of stay, with a higher median length of stay in the before school closure subgroup compared with the

TABLE 2.
Study Group Characteristics

Characteristic	Before School Closure[a] (n = 50,783)	After School Closure[a] (n = 59,635)	P[b]
Female[c]	22,542 (44.4%)	26,850 (45.0%)	0.035
Age			
Neonate (birth to 29 d)	1,679 (3.3%)	1,725 (2.9%)	< 0.001
Infant (29 d to < 2 yr)	19,563 (38.5%)	18,614 (31.2%)	
Child (2 to < 6 yr)	10,089 (19.9%)	11,970 (20.1%)	
Child (6 to < 12 yr)	8,646 (17.0%)	11,494 (19.3%)	
Adolescent (12 to < 18 yr)	10,806 (21.3%)	15,832 (26.6%)	
Trauma	2,388 (4.7%)	4,695 (7.9%)	< 0.001
Postoperative	10,967 (21.6%)	16,135 (27.1%)	< 0.001
PIM2 probability of death	0.79 (0.20–1.23)	0.84 (0.22–1.52)	< 0.001
ICU length of stay, d	1.85 (0.96–3.91)	1.66 (0.92–3.65)	< 0.001
ICU survival	49,837 (98.1%)	58,275 (97.7%)	< 0.001
Standardized Mortality Ratio (observed/ expected deaths) (PIM2)	0.85 (0.80–0.91)	0.88 (0.83–0.93)	0.46

PIM2 = Pediatric Index of Mortality 2.
[a]Data from all three years; 2018, 2019, and 2020.
[b]p values based on chi-square or Fisher exact test for categorical variables and Mann-Whitney test for continuous variables. For the standardized mortality ratio (observed/ expected deaths), the p is based off of a z score.
[c]Missing for three cases, percentages are out of total nonmissing.
Data are shown as n (%) and median (interquartile range).

after school closure subgroup (1.85 d [IQR, 0.96–3.91 d] vs 1.66 d [0.92–3.65 d]; $p < 0.001$). No significant difference was seen in the standardized mortality ratio.

We found a statistically significant decrease in respiratory illnesses (bronchiolitis, asthma, and pneumonia) following school closure (**Fig. 1**). Bronchiolitis exhibited a significant change in PICU admission pattern following school closure. Up until 2 days after school closure, the ratio of bronchiolitis admissions during COVID versus pre-COVID remained close to equivalent and then significantly decreased after day +2. This significant decrease in slope, or inflection point, indicated a decrease in PICU admissions that persisted for 17 days, with a second inflection point identified at day +19. This second inflection point indicated a "leveling-off" of the admission ratio. These data indicate that within days of school closure, significantly fewer patients were being admitted to the PICU for bronchiolitis. This trend continued for over 2 weeks, following which the ratio reached a plateau between 0 and 0.2. PICU admissions due to bronchiolitis decreased by 82% in less than 3 weeks following national school closure.

Pneumonia also showed a significant change in PICU admission pattern after school closure. There was an inflection point observed 8 days following the identified date of school closure, signifying a significant decrease in PICU admissions. This decrease continued until day +43 where a second inflection point was found and showed a positive change in slope. Compared with bronchiolitis, pneumonia admissions took longer to start decreasing from equivalence (6 d)

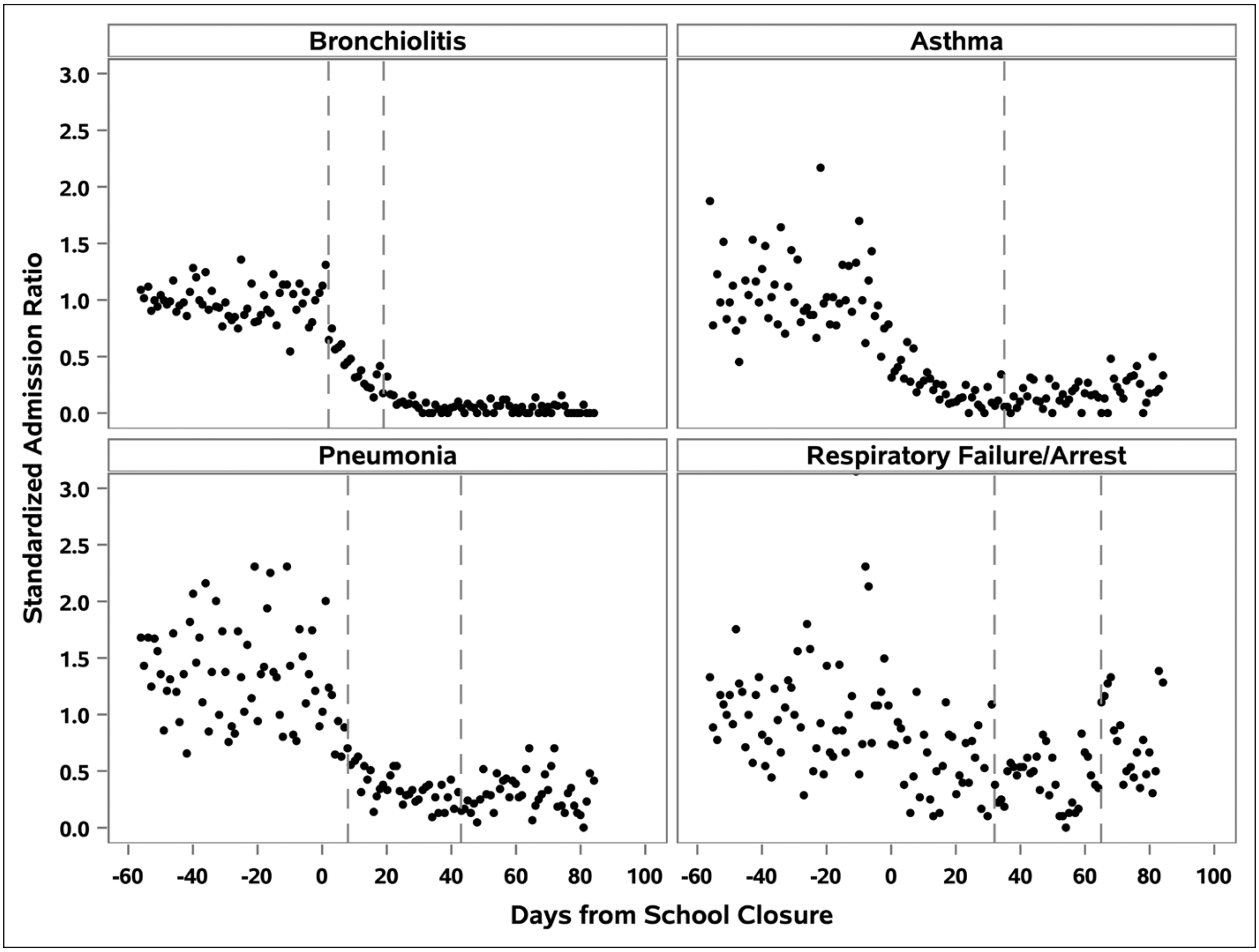

Figure 1. School closure effect on respiratory diseases. Scatter plot illustrating the ratio of PICU admissions for disease categories in 2020 over admissions for that category in 2018–2019 on the *y*-axis, and days relative to school closure date on the *x*-axis. The *vertical lines* in each scatter plot define the time point at which a statistically significant shift in the slope of the least squares regression line for admission ratio was identified. Ratios >1 reflect an increase in PICU admissions in 2020 compared with 2018–2019.

and longer to plateau (6 wk), and the volume of PICU admissions decreased by a smaller percentage (76%).

Asthma was the third respiratory disease to show a significant decrease in the number of PICU admissions following school closure, reaching an inflection point at 35 days after school closure, and the volume of PICU admissions decreased by 76%. Respiratory failure/arrest, including acute respiratory distress syndrome, showed a significant but less prominent decrease in PICU admission at day +32 with an increasing slope at day +65 with a decrease of approximately 25%.

The remaining diagnoses were examined to identify potential changes in PICU admission trends following school closure (**Fig. 2**). The scatter plots identify no visually apparent changes in PICU admission ratio before and after school closure, and the employed statistical methods identified no significant changes for any of these PICU admission diagnoses.

DISCUSSION

We used public health data describing the timing of school closures around the country to create normalized admission diagnosis ratios before and after a nationwide public health intervention and found that public health school closures to mitigate the spread of COVID-19 disease were associated with a decline in the prevalence of severe respiratory diseases warranting admission to 81 PICUs in the United States. Severe, noninfectious disease trends were also evaluated and found to have no significant changes associated with school closures.

Our data align with other studies (16, 17), showing decreases in pediatric hospital admissions, especially those due to respiratory illnesses between January and June 2020. As opposed to these studies, we evaluated the temporal relationship of PICU admissions and school closures. In our data, bronchiolitis admissions to PICU dropped most rapidly after school closure. Pneumonia had a later drop at 8 days. There was not a statistically significant decrease in asthma early after school closures. The data also demonstrate a later but less prominent impact to respiratory failure/arrest, which includes acute respiratory distress syndrome and has other nonviral etiologies.

The timelines for each disease process to exhibit a significant change is also intriguing. Bronchiolitis is caused by a viral infection in children under 2 years old. Childcare utilization dropped off significantly at the same time as school closure but increased to lower than prepandemic levels in the weeks to months following school closure (18). Although school closures were mandated nationwide, daycare closures were not mandated. The abrupt drop in patients with bronchiolitis was most likely related to closing of some daycare institutions, decreased spread from older siblings resulting from school closures, and other protective measures implemented by parents. However, our data demonstrate a sustained decrease in PICU admissions for bronchiolitis, suggesting that school-aged children serve as an important reservoir for transmission of respiratory viruses causing bronchiolitis. Pneumonia has a longer course of illness (19) with time needed for viral replication and progression into the lower respiratory tract, immune responses to pathogens, or bacterial invasion (20) into the lung parenchyma. This could explain the 6-day difference between significant changes in admission ratios.

In the United States, federal government agencies offered guidance for public health emergencies; however, public health policies and responses occurred at the local and state levels (21). As was the case in the COVID-19 pandemic, there were variations in the timing of these interventions. We developed a methodology, adapting statistical analysis from quality improvement with process control, to standardize the evaluation of a public health intervention (school closure) on a large cohort of a severe phenotype (critically ill children). To our knowledge, our attempt is the first to do so at this scale and may serve as a model to investigate the public health aspects of widespread societal changes.

Data surrounding the impact of school closure on emerging infectious diseases are variable and comprise local experiences, mathematical modeling, and review articles (22–28). Markel et al (29) studied the impact of nonpharmaceutical interventions, including school closure, during the 1918–1919 influenza pandemic across 43 U.S. cities and showed that early, sustained, and layered nonpharmaceutical interventions decreased mortality. One systematic review (30) on school closures for both seasonal and epidemic influenza supports the use of school closure to mitigate epidemic peak and size. It recognizes that duration of closure should be dependent on attack rate, duration of infectiveness, and social

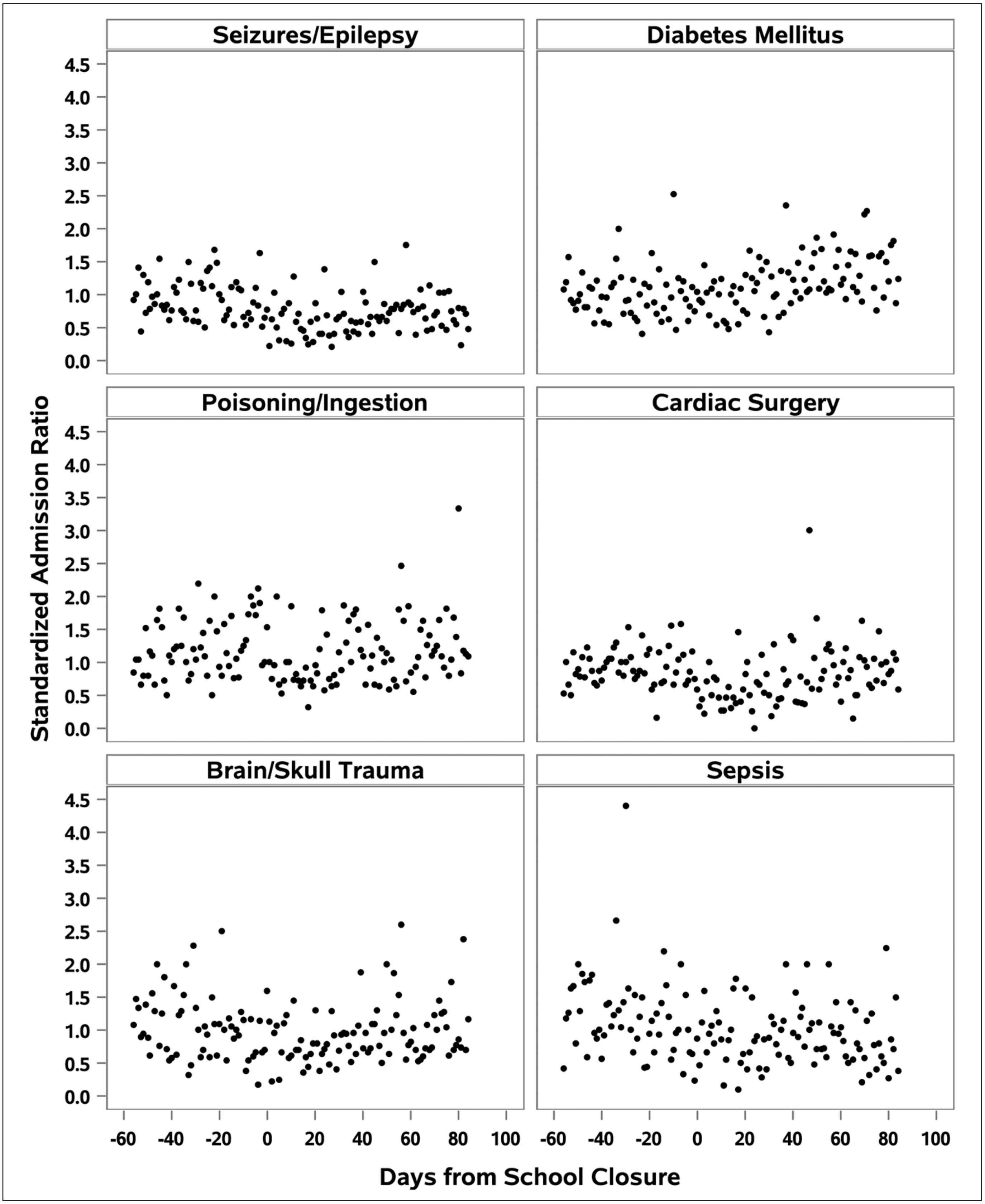

Figure 2. School closure effect on common nonrespiratory diseases. Scatter plot illustrating the ratio of PICU admissions for disease categories in 2020 over admissions for that category in 2018–2019 on the *y*-axis, and days relative to school closure date on the *x*-axis. Ratios >1 reflect an increase in PICU admissions in 2020 compared with 2018–2019.

contact behaviors. Although favoring the use of school closures in severe pandemics, Cauchemez et al (31) advocate for a balanced approach, citing unintended school closure consequences such as loss of productivity with work absenteeism due to lack of childcare, lack of access to school-based food programs, risks associated with self-care (increased peer pressure/high risk behaviors and development of social and behavioral problems without adult supervision), dysfunction of healthcare systems due to staffing shortages, and the widening of existing health and socioeconomic disparities.

Although there are diagnoses in the PICU that may be subject to the effects of wide societal shifts, we did not identify other diagnoses that demonstrated the same dramatic shifts as respiratory illnesses. Although overall PICU utilization appeared to increase for diabetic ketoacidosis during the COVID-19 pandemic in our data, we identified no single time point after school closures after which the admission rate changed. This suggests a delayed effect outside of the timeframe of these data, a more gradual onset of change, or that school closure did not significantly affect the incidence of pediatric diabetic ketoacidosis. Status epilepticus is another disease with a theoretic risk of increasing due to school closures if maintenance antiepileptic medications are withheld or decreasing if episodes are triggered by infectious disease. However, our data showed no significant changes in the incidence of status epilepticus related to school closures.

Two other common reasons for admission to the PICU that were analyzed in this study were traumatic injuries and ingestions. In U.S. emergency departments, initially, there were decreased visits associated with suicide attempt early in the pandemic, but the rate of visits increased to higher levels in female patients 12–17 years old when compared with prepandemic rates within a few months (32). COVID-related job loss or financial instability, stressors associated with school closure (lack of childcare and lack of access to mandated child abuse reporters), and shelter-in-place orders (increased exposure to a potential violent partner/parent) raised the concern of increased interpersonal violence, including child abuse (33). We found no significant changes in the incidence of traumatic injuries or ingestions requiring PICU admission in our data relative to school closure. Although there are several possible explanations for the lack of significant changes in these disease categories, the most likely is that our time of interest (12 wk post school closure) may not be a long enough time to detect significant changes.

Although the strengths of this study include the large number of patients representing a wide geographic area and the novel use of normalized public health intervention dates across the entire country, there are several limitations. First, our retrospective database study can elucidate associations but cannot define causal pathways with certainty. Second, significant bias may exist in comparing our database findings against many other nonpharmaceutical public health measures undertaken at the time of school closures. For instance, the observed associations may be attributable to social distancing, mask mandates, or increased hand hygiene as opposed to school closures. Finally, large database sets inherently have the potential for data entry error and are subject to issues with interrater reliability, but VPS has measures in place to assure quality data (34).

CONCLUSIONS

School closures are associated with a dramatic reduction in the prevalence of severe respiratory disease requiring PICU admission. Thus, school closure may be an effective tool to mitigate future pandemics but should be balanced with potential academic, economic, mental health, and social consequences.

ACKNOWLEDGMENTS

VPS data was provided by Virtual Pediatric Systems, LLC. No endorsement or editorial restriction of the interpretation of these data or opinions of the authors has been implied or stated. This article has been reviewed by the VPS Research Committee.

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Dr. Lin's institution received funding from the Health Resources and Services Administration and Assistant Secretary for Preparedness and Response. Dr. Klein received funding from the University Hospitals of Cleveland Linsalata Family Chair in Pediatric Critical Care and Emergency Medicine; she disclosed that she is being paid for her time as a member of the research team. Dr. Rotta received funding from Vapotherm, Breas US, and Elsevier. Dr. Remy received support for article research from the National Institutes of Health. Dr. Shein received funding from law firms for providing expert testimony and legal review. The remaining authors have disclosed that they do not have any potential conflicts of interest.

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