Hospitalizations for all-cause pediatric acute respiratory diseases in Alberta, Canada, before, during, and after the COVID-19 pandemic: a population-level retrospective cohort study from 2010 to 2024

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Summary

Background This population-level retrospective cohort study measured seasonal patterns of pediatric hospitalizations, pediatric intensive care unit (PICU) admissions, and average age of children diagnosed with acute respiratory diseases (ARD) during pre-pandemic, COVID-19 pandemic, and late/post-pandemic periods.

Methods From September 2010 through August 2024, all hospitalizations for ARD among children <18 years old were identified from the provincial Discharge Abstract Database, in Alberta, Canada. Seasonal autoregressive integrated moving average (SARIMA) models were developed based on pre-pandemic trends and predicted expected weekly outcomes with 95% confidence intervals (95% CI) from March 2020 onward. Observed and expected outcomes with 95% CI were compared to measure impacts during peak seasons.

Findings There were 52,839 ARD hospitalizations: 16,003 (30.29%) bronchiolitis, 7958 (15.06%) influenza-like illness, 14,366 (27.19%) pneumonia, 2989 (5.66%) croup, 10,266 (19.43%) asthma exacerbation, and 1257 (2.38%) COVID-19. Further, 4433 (8.39%) hospitalizations included a PICU admission. During the pre-pandemic period, hospitalizations for ARD had a biennial pattern, where the peak incidence was highest every other winter season. During the pandemic and late/post-pandemic periods, the average weekly incidence of hospitalization for ARD/100,000 children decreased 91.25% during winter 2020–2021 (1.03 observed vs. 11.81 [95% CI 7.30, 16.33] expected), increased 47.98% during winter 2022–2023 (18.06 observed vs. 12.20 [95% CI 7.06, 17.34] expected), and returned near pre-pandemic incidence during winter 2023–2024 (12.87 observed vs. 11.87 [95% CI 6.08, 17.67] expected) compared with incidence predicted by the SARIMA model. During winter 2022–2023 when hospitalizations surged, there was no significant change in the average weekly incidence of PICU admissions for ARD/100,000 children (2.07 observed vs. 1.26 [95% CI 0.26, 2.27] expected), nor percent PICU admissions (10.21% observed vs. 10.11% [95% CI 5.50, 14.73] expected), nor in average age (31.95 months observed vs. 34.20 months [95% CI 25.89, 42.52] expected).

Interpretation Hospitalizations for pediatric ARD decreased dramatically during winter 2020–2021, surged during winter 2022–2023, and returned near pre-pandemic incidence during winter 2023–2024. There was no lasting change in PICU admissions nor average age. Ongoing surveillance will describe the evolving seasonal pattern of ARD during the post-pandemic period.

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Research in context

Evidence before this study

Acute respiratory diseases (ARD)—including bronchiolitis, influenza-like illness, pneumonia, croup, asthma exacerbation, and COVID-19—are common causes of pediatric hospitalization. Hospitalizations for pediatric ARD typically follow seasonal patterns that were disrupted in March 2020 by the COVID-19 pandemic. A literature search in PubMed on October 10, 2024 identified studies with search terms "(pediatric* OR paediatric*) AND (bronchiolitis OR influenza OR pneumonia OR croup OR asthma) AND (hospital admission*) AND (COVID* OR SARS-CoV*)" with publication years 2020 onward. Most studies focus on a single pathogen or clinical syndrome, most commonly RSV or bronchiolitis, and reported that RSV or bronchiolitis associated hospitalization significantly decreased in 2020–2021, began to rise in 2021–2022, had an off-season peak in spring and summer 2022, and significantly increased in 2022–2023. Some studied suggest that the surge in RSV cases during the late/post-pandemic years can be attributed to increased pathogen testing and detection.

Added value of this study

This study is the first to analyse the impact of the COVID-19 pandemic on hospitalization and pediatric intensive care unit (PICU) admissions for the most common pediatric ARD overall and individually (i.e., bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbations). By measuring admissions based on clinical syndromes, this study reduces bias related to changes in pathogen testing practices. During the pre-pandemic period (September 5, 2010–February 29, 2020), hospitalizations for all-cause pediatric ARD showed a biennial pattern, where the peak incidence was highest every other winter. Individually, bronchiolitis and croup followed biennial patterns with alternating high peak years. Influenza-like illness and pneumonia had annual peaks. Asthma had a unique annual pattern with high peaks each autumn and lower peaks in winter.

The pandemic period (March 1, 2020–September 3, 2022) includes the interval when non-pharmaceutical interventions were introduced. In winter 2020–2021, seasonal patterns were disrupted, as evidenced by decreased hospitalizations and PICU admissions for ARD overall and individually. The late/post-pandemic period (September 4, 2022–August 31, 2024) includes two full years after non-pharmaceutical interventions were discontinued. In winter 2022–2023, hospitalizations and PICU admissions for bronchiolitis significantly exceeded expected levels based on pre-pandemic trends. Admissions for influenza-like illness, pneumonia, and asthma exacerbation all exceeded expected levels, though not significantly. In contrast, admissions for croup remained below expected levels. By winter 2023–2024, hospitalizations and PICU admissions for ARD overall and individually returned to expected pre-pandemic levels.

Implications of all the available evidence

The COVID-19 pandemic and non-pharmaceutical interventions that temporarily reduced transmission of all respiratory pathogens, had significant impacts on the seasonal patterns of pediatric ARD hospitalization and PICU admissions. There was a universal decline in admissions during winter 2020–2021, a surge in winter 2022–2023 particularly for bronchiolitis, and a return to pre-pandemic levels by winter 2023–2024. By measuring clinical syndromes rather than cases based on pathogen test results, this study minimizes bias due to changes in testing practices. Ongoing monitoring will determine if seasonal patterns are re-established, helping to inform healthcare planning for future seasonal surges.

Introduction

Pediatric acute respiratory diseases (ARD) including bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbation are the most common indications for pediatric hospital admission.[1] ARD are caused or triggered by respiratory pathogens,[2] with seasonal transmission patterns that peak annually during winter months in the northern hemisphere.[3,4] These seasonal patterns were interrupted with the emergence of a novel coronavirus SARS-CoV-2, and subsequent implementation of non-pharmaceutical interventions aimed at reducing respiratory pathogen transmission.[5–7] Consequently, the relationship between the COVID-19 pandemic and seasonal pattern of pediatric ARD is evolving and has implications for readiness planning by healthcare funders, public health services (e.g.,

surveillance, testing, vaccines and public communication), and acute health care system planning (e.g., drug supplies, surge capacity in hospitals).[8]

Currently published studies largely focus on the changing epidemiology of a single pathogen or clinical syndrome before and during the COVID-19 pandemic. Respiratory syncytial virus (RSV) is most studied, as RSV is the most common cause of bronchiolitis and the leading cause of hospitalization among children less than 5 years old.[7,9–11] Additional studies have described the epidemiology of respiratory viruses such as influenza, parainfluenza, and clinical diagnoses such as influenza-like illness, pneumonia, and croup.[12–14] However, these studies did not measure pediatric hospitalizations for all-cause ARD.

Monitoring pediatric admissions to hospital and intensive care for ARD captures symptomatic children requiring admission based on clinical assessment of respiratory distress and other clinical features, rather than measuring positive microbiologic test results than can be bias due to variations in pathogen testing practices over time.[15] Moreover, multiple respiratory pathogens are associated with each clinical presentation and these clinical diagnoses can present with overlapping symptoms and may be misdiagnosed in specific age groups, such as bronchiolitis and asthma among children between 12 and 24 months of age. Monitoring admissions for the most common ARD limits misclassification and increases comprehensiveness.

This study describes seasonal patterns of pediatric hospitalization for ARD overall and for bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbations individually, from September 5, 2010, to August 31, 2024. We measured the impact of the COVID-19 pandemic on the weekly incidence of hospitalizations to quantify healthcare use, the weekly incidence and percent of pediatric intensive care unit (PICU) admissions to infer clinical severity, and the weekly average age at discharge to characterise the affected population.

Methods

Ethics

The research protocol was reviewed and approved by the University of Calgary Conjoint Health Research Ethics Board (Ethics ID: REB22-1572). The study is reported according to the RECORD guidelines.

Study design and setting

This population-level retrospective cohort study was conducted using 14 years of hospital records from all residents of Alberta, a Canadian province with a growing population from 3,705,715 in 2010 to 4,681,333 in 2024 (Supplemental Table S10).[16] All residents have access to universal healthcare allowing the administrative data to capture all pediatric hospitalizations at Alberta Children's Hospital, Stollery Children's Hospital, and 95 other hospitals that provided pediatric care. Only Alberta Children's Hospital and Stollery Children's Hospital have a PICU, though pediatric patients rarely admitted at other intensive care units in Alberta are included.

Data sources

The Discharge Abstract Data is an administrative database containing demographic and clinical information for all acute care hospital encounters.[17] The Discharge Abstract Data is the most complete longitudinal dataset for acute care in Alberta, as reporting is mandated to the Canadian Institute for Health Information. Alberta population estimates, stratified by age and sex, are made publicly available and maintained by the office of statistics and information Government of Alberta.[16] The Oxford COVID-19 Government Response Tracker (OxCGRT) is publicly available data procured by a research group at the Blavatnik School of Government, University of Oxford.[18] Weekly data regarding government and public health related pandemic policies were systematically collected between January 1, 2020, and December 31, 2022, form 183 countries and their jurisdictions, including Canada and its provinces and territories.

Inclusion criteria

The study included all children (<18 years old) discharged from hospital with an ARD between September 5, 2010, and August 31, 2024, who reside in Alberta, Canada based on postal code. ARD included bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbation. Additionally, children discharged from hospital with COVID-19 were included between March 1, 2020, and August 31, 2024. Case definitions for each pediatric ARD were developed with ICD-10 codes in the primary diagnostic position based on published validation studies and sensitivity analyses (Supplemental Table S7).[17,19–23]

Variables of interest

The primary outcome was healthcare utilization, measured through weekly incidence of hospitalizations per 100,000 children (<18 years of age) for ARD overall and individually. For bronchiolitis and croup respectively, incidences are presented per 100,000 children <2 years and <6 years of age as these clinical diagnoses are age dependent.[24] Weekly incidence of hospitalizations was calculated using the number of hospital discharges for ARD divided by the age-appropriate population denominator (Supplemental Table S10).[16]

Secondary outcomes of interest were the clinical severity of ARD, as measured by weekly incidence and percent PICU admissions, and the age of the affected population, as measured by weekly average age at

discharge. Weekly percent PICU admissions was calculated using the number of PICU admissions for ARD divided by the number of hospitalizations for ARD and represented using a 13-week moving average. The Discharge Abstract Data includes a variable for hours spent in a special care unit.[25] Hospitalizations where the patient spent any amount of time in a special care unit were classified as admissions to the PICU. Patient age in months was calculated using the difference between the date of birth and date of hospital discharge, weekly averages were generated and represented using a 13-week moving average. Weeks were defined as epidemiological weeks, standardized by the United States Center for Disease Control and Prevention.[26]

Population exposure to non-pharmaceutical interventions in Alberta was quantified using a stringency index developed and validated by OxCGRT.[18] The stringency index combines nine indicators—one indicator regarding public information campaigns and eight indicators related to closures and movement restrictions. The indicators are combined into one index on a scale from 0 to 100, where 100% is the most stringent.

Time periods

The pre-pandemic period includes 9.5 years of data from September 5, 2010, to February 29, 2020. Onset was informed by the start of the influenza surveillance year on September 5, 2010 (start of epidemiological week 36 in 2010).[27] The COVID-19 pandemic period includes 2.5 years of data from March 1, 2020, to September 3, 2022. Onset was informed by the World Health Organization declaration of the SARS-CoV-2/COVID-19 global pandemic on March 11, 2020, the Alberta government declaration of the public health state of emergency on March 17, 2020, and resulting implementation of non-pharmaceutical interventions with accompanying increase in the stringency index from approximately 10% to 75% by April 5, 2020.[18,28] Ending was informed by discontinuation of mandatory non-pharmaceutical interventions in by June 14, 2022 with accompanying decrease in stringency index below 10% by the end of September 2022.[28] The late/post-pandemic period includes 2 years of data from September 4, 2022, to August 31, 2024. Onset was informed by the start of the academic school year and influenza surveillance year.

Statistical analysis

Time series analysis, specifically seasonal autoregressive integrated moving average (SARIMA) models were used to account for the autocorrelation and seasonal patterns in our data.[29] SARIMA models are deterministic—given the same historic data the model will predict the same forecasted values. SARIMA modeling was done for ARD overall and stratified for bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbations individually. We fit twenty-four SARIMA models (one for each combination of outcome measure and ARD of interest) to our data in the pre-pandemic period. SARIMA model parameters were selected based on Akaike Information Criterion using the *auto.arima* function in the forecast package in R (Supplemental Table S8).[30] Then, each SARIMA model was used to forecast expected outcomes with 95% confidence intervals (95% CI) during the COVID-19 pandemic and late/post-pandemic periods. The expected outcomes generated the reference group, in other words a counterfactual assuming the prior seasonal pattern continued in the absence of COVID-19.

The impact of the COVID-19 pandemic was measured by comparing observed and expected outcomes with ratios and percent change each season. Statistical significance was defined by an observed outcome outside the 95% CI of the expected outcome as predicted by the SARIMA model. A 52-week year contains four 13-week quarters, thus the winter season was defined as the 13-week period between December and February (i.e., start of week 49 to the end of week 9) because prior surveillance showed the incidence RSV and influenza reliably peaks between December and February annually.[4] Analyses were conducted in R version 4.4.0 (2024-04-24) and R studio version 2024.04.1 + 748 using the dplyr, tidyr, MMWRweek, forecast, and ggplot2 packages.

Role of the funding source

There was no funding source for this study.

Results

Seasonal patterns of pediatric ARD

There were 52,839 hospitalizations for ARD among children in Alberta over the 14-year study period; 13,718 (25.96%) at Alberta Children's Hospital, 12,882 (24.38%) at Stollery Children's Hospital, and the remaining 26,239 (49.66%) at 95 other hospitals that provide pediatric care. Of the 52,839 hospitalizations, 16,003 (30.29%) were for bronchiolitis, 7958 (15.06%) for influenza-like illness, 14,366 (27.19%) for pneumonia, 2989 (5.66%) for croup, 10,266 (19.43%) for asthma exacerbation, and 1257 (3.55%) for COVID-19 (Table 1; Fig. 1).

During the pre-pandemic period, hospitalizations for ARD generally had a biennial pattern, where the incidence increased every winter season and peak incidence was highest every other winter (Fig. 2). The average weekly incidence of hospitalizations per 100,000 children was 10.74 (95% CI 10.04, 11.45) in low peak winter seasons, and 12.74 (95% CI 11.82, 13.66) in high peak winter seasons, an 18.62% increase.

Considered individually, biennial peaks in hospitalization were observed for bronchiolitis and croup. For bronchiolitis, the average weekly incidence per 100,000 children <2 years old was 32.21 (95% CI 28.53, 35.89) in

	Pre-pandemic period	Pandemic period	Late/post-pandemic period	Study period
	September 5, 2010–February 29, 2020	March 1, 2020–September 3, 2022	September 4, 2022–August 31, 2024	September 5, 2010–August 31, 2024
	Start of week 36–End of week 9	Start of week 10–End of week 35	Start of week 36–End of week 35	Start of week 36–End of week 35
	9 years 6 months	2 years 6 months	2 years	14 years
All acute respiratory diseases <18 years old				
Number of hospitalizations	36,906	5636	10,297	52,839
Number and percent (%) of PICU admissions	2931 (7.94%)	567 (10.06%)	935 (9.08%)	4433 (8.39%)
Mean age in months (SD)	39.88 (12.48)	47.09 (18.84)	40.07 (10.18)	41.20 (13.82)
Mean age in years (SD)	3.32 (1.04)	3.92 (1.57)	3.34 (0.85)	3.43 (1.15)
Bronchiolitis <2 years old				
Number of hospitalizations	11,015	1590	3398	16,003
Number and percent (%) of PICU admissions	1049 (9.52%)	234 (14.72%)	451 (13.27%)	1734 (10.84%)
Mean age in months (SD)	8.39 (2.40)	9.24 (3.89)	9.04 (2.42)	8.62 (2.72)
Mean age in years (SD)	0.70 (0.20)	0.77 (0.32)	0.75 (0.20)	0.72 (0.23)
influenza-like illness <18 years old				
Number of hospitalizations	5426	805	1727	7958
Number and percent (%) of PICU admissions	391 (7.21%)	47 (5.84%)	133 (7.70%)	571 (7.18%)
Mean age in months (SD)	36.65 (17.92)	36.81 (31.71)	41.85 (13.58)	37.43 (20.39)
Mean age in years (SD)	3.05 (1.49)	3.07 (2.64)	3.49 (1.13)	3.12 (1.70)
Pneumonia <18 years old				
Number of hospitalizations	11,140	1038	2188	14,366
Number and percent (%) of PICU admissions	598 (5.37%)	67 (6.45%)	161 (7.36%)	826 (5.75%)
Mean age in months (SD)	50.78 (15.90)	61.15 (38.73)	57.28 (16.37)	53.52 (22.10)
Mean age in years (SD)	4.23 (1.33)	5.10 (3.23)	4.77 (1.36)	4.46 (1.84)
Croup <6 years old				
Number of hospitalizations	2402	221	366	2989
Number and percent (%) of PICU admissions	218 (9.08%)	25 (11.31%)	33 (9.02%)	276 (9.23%)
Mean age in months (SD)	22.71 (8.31)	20.98 (10.19)	19.68 (8.89)	22.03 (8.72)
Mean age in years (SD)	1.89 (0.69)	1.75 (0.85)	1.64 (0.74)	1.84 (0.73)
Asthma exacerbation <18 years old				
Number of hospitalizations	6923	1298	2045	10,266
Number and percent (%) of PICU admissions	675 (9.75%)	102 (7.86%)	114 (5.57%)	891 (8.68%)
Mean age in months (SD)	66.84 (17.42)	64.16 (23.72)	63.42 (11.22)	65.89 (17.97)
Mean age in years (SD)	5.57 (1.45)	5.35 (1.98)	5.29 (0.94)	5.49 (1.50)
COVID-19 < 18 years old				
Number of hospitalizations	NA	684	573	1257
Number and percent (%) of PICU admissions	NA	92 (13.45%)	43 (7.50%)	135 (10.74%)
Mean age in months (SD)	NA	65.50 (49.74)	27.48 (22.73)	45.80 (42.60)
Mean age in years (SD)	NA	5.46 (4.15)	2.29 (1.89)	3.82 (3.55)

Weeks were defined as epidemiological weeks, standardized by the United States Center for Disease Control and Prevention.[26] Pediatric Intensive Care Unit (PICU). Standard deviation (SD).

Table 1: **Distribution of hospitalizations for pediatric acute respiratory diseases during the pre-pandemic, COVID-19 pandemic, and late/post-pandemic periods in Alberta, Canada.**

low peak years, and 50.51 (95% CI 45.10, 55.92) in high peak years, a 56.83% increase (Supplemental Fig. S1). For croup, the peak winter seasons alternated with bronchiolitis and were of lower magnitude (Supplemental Fig. S4). The average weekly incidence per 100,000 children <6 years old varied from 1.58 (95% CI 1.42, 1.74) to 2.43 (95% CI 2.05, 2.80), a 34.76% increase.

Hospitalizations for influenza-like illness and pneumonia peaked annually in the winter, with an average weekly incidence of 1.74 (95% CI 1.62, 1.87) and 3.48 (95% CI 3.27, 3.69) per 100,000 children <18 years old

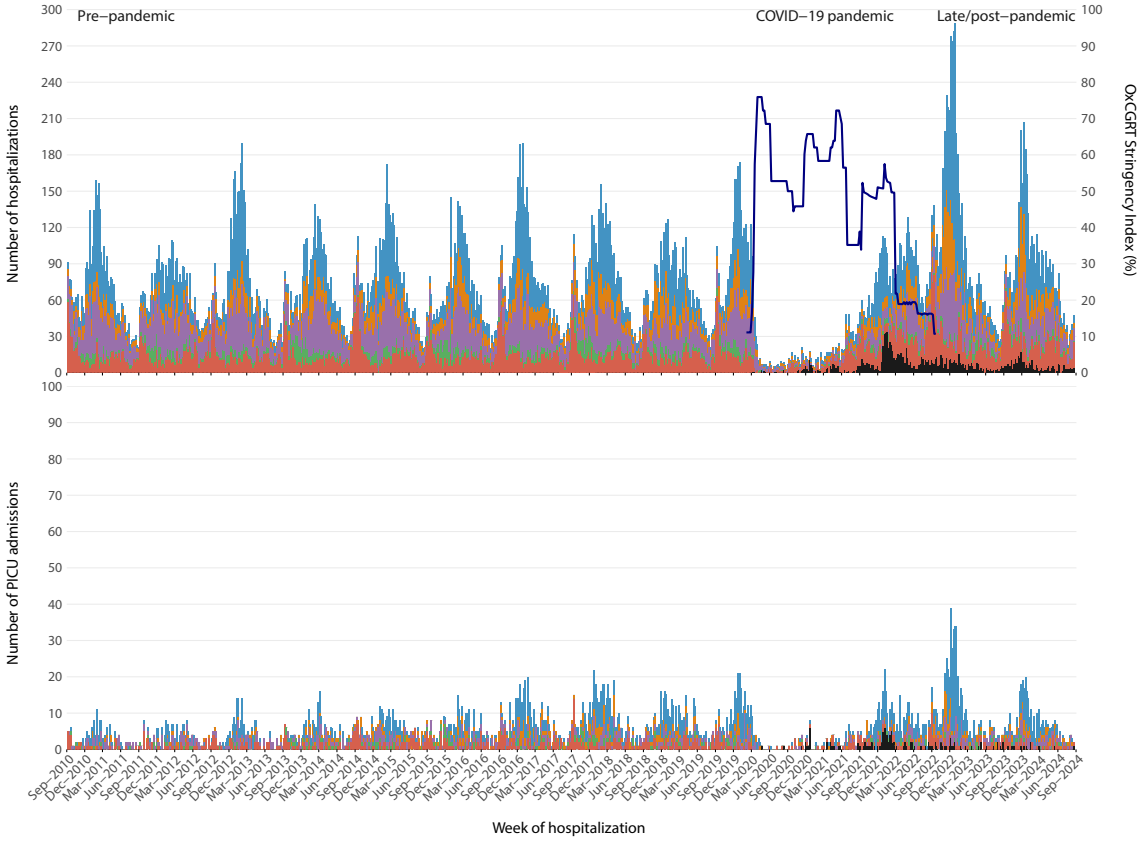

Fig. 1: **Number of pediatric hospitalizations including pediatric intensive care unit (PICU) admissions for acute respiratory diseases among children younger than (<) 18 years old relative to the OxCGRT Stringency Index in Alberta, Canada, September 5, 2010–August 31, 2024**. **(Top)** The number of hospitalizations for acute respiratory diseases (N = 52,839) includes bronchiolitis among children <2 years old (blue, N = 16,003; 30.29%), influenza-like illness among children <18 years old (yellow, N = 7958; 15.06%), pneumonia among children <18 years old (purple, N = 14,366; 27.19%), croup among children <6 years old (green, N = 2989; 5.66%), and asthma exacerbation among children <18 years old (orange, N = 10,266; 19.43%). Additionally, hospitalizations for COVID-19 among children <18 years old were included from March 1, 2020 to August 31, 2024 (black, N = 1257; 2.38%). **(Bottom)** The number of hospitalizations for acute respiratory diseases (N = 52,839) which included a PICU admission (N = 4433; 8.39%). Weeks were defined as epidemiological weeks, standardized by the United States Center for Disease Control and Prevention.[26] Population exposure to non-pharmaceutical interventions in Alberta was quantified using a stringency index developed and validated by The Oxford COVID-19 Government Response Tracker (OxCGRT), on a scale from 0 to 100, where 100% is the most stringent.[18]

respectively. Hospitalizations for asthma exacerbations had a unique seasonal pattern, with an annual average weekly peak incidence of 3.67 (95% CI 3.16, 4.18) each September, compared with an average weekly incidence of 1.05 (95% CI 0.97, 1.13) during winter seasons (Supplemental Fig. S5).

Impact of the COVID-19 pandemic on hospitalizations for pediatric ARD

During the pandemic period, non-pharmaceutical interventions were implemented in Alberta and the stringency index increased from about 10% in March 2020 to 75% by April 2020 (Fig. 1). Hospitalizations for ARD abruptly decreased and remained low during the 2020–2021 winter season (Table 2; Fig. 2). The observed average weekly incidence of hospitalization for ARD per 100,000 children decreased to 1.03 compared with the expected incidence 11.81 (95% CI 7.30, 16.33)—a 91.25% significant decrease for ARD including a 96.47% decrease in bronchiolitis, 92.99% decrease in influenza-like illness, 92.21% decrease in pneumonia, 96.44% decrease in croup, and 81.04% decrease in asthma exacerbation (Supplemental Tables S1–S5; Supplemental Figs. S1–S5).

The stringency index decreased to about 35% over the summer 2021, varied around 50% over autumn 2021 and winter 2021–2022, and decreased to about 20% in spring 2022 (Fig. 1). During the 2021–2022 winter season, the observed average weekly incidence of hospitalization for ARD per 100,000 children was 8.74

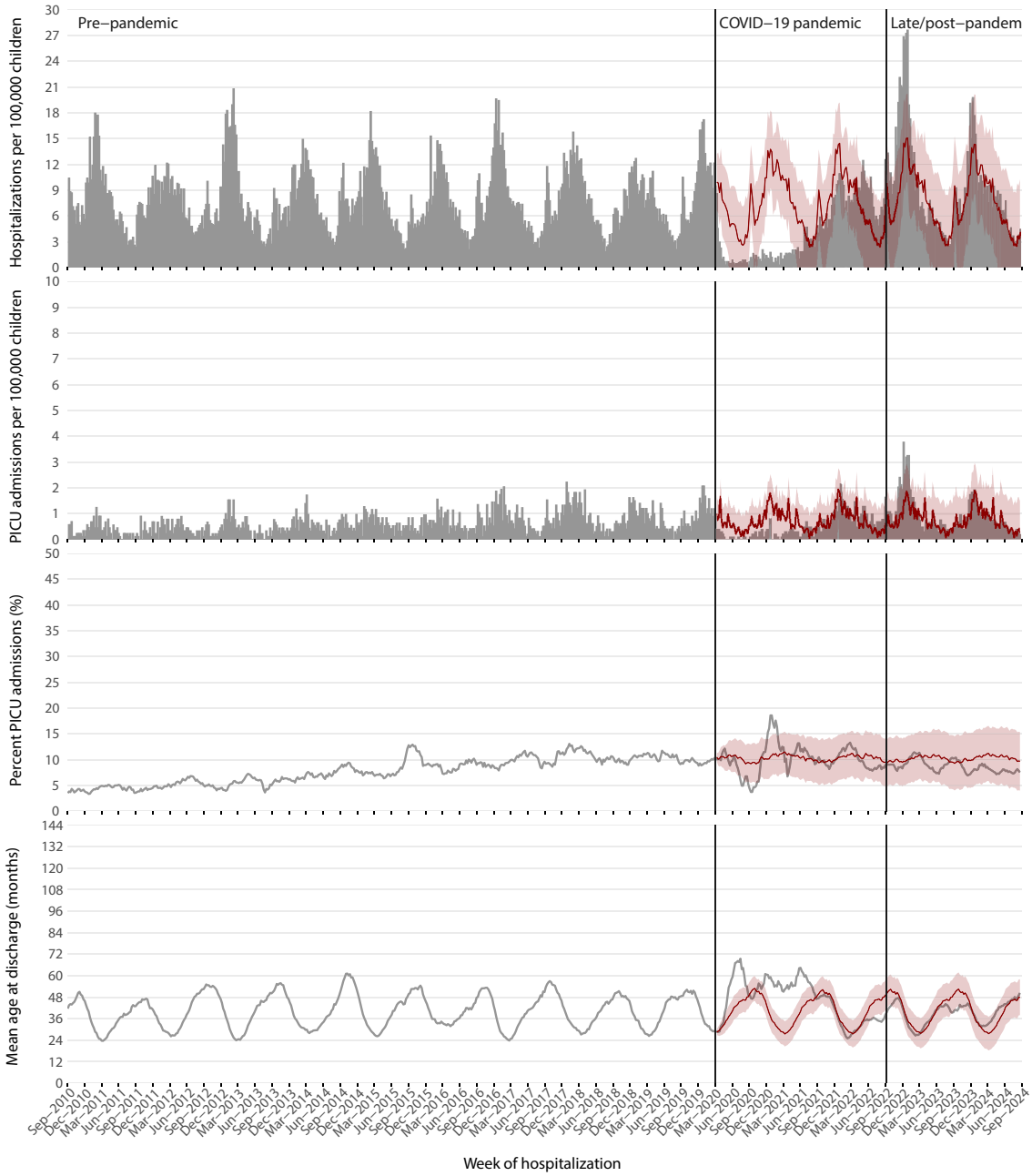

***Fig. 2*: Seasonal patterns of observed and expected outcomes for acute respiratory disease among children younger than (<) 18 years old in Alberta, Canada, September 5, 2010–August 31, 2024.** Seasonal autoregressive integrated moving average (SARIMA) models were fit to data from the pre-pandemic period (September 5, 2010–February 29, 2020). Then SARIMA models predicted expected point estimates (red line) with 95% confidence intervals (95% CI) (red ribbon) during the COVID-19 pandemic period (March 1, 2020–September 3, 2022) and the late/post-pandemic period (September 4, 2022–August 31, 2024). Please see the Supplemental Table S8 for an explanation of each SARIMA (p.d.q) (P,D,Q)[s] model parameter. **(First row)** weekly incidence of hospitalization for acute respiratory diseases among children <18 years old, observed (grey bars) and expected point estimate and 95% CI modelled with SARIMA (2,0,2) (2,1,0)[52] (red line with ribbon). **(Second row)** weekly incidence of pediatric intensive care (PICU) admissions among children <18 years old, observed (grey bars) and expected point estimate and 95% CI modelled with SARIMA (1,0,2) (1,1,0)[52] (red line with ribbon). **(Third row)** weekly percent pediatric intensive care unit (PICU) admissions of all hospitalizations as a 13-week moving average, observed (grey line) and expected point estimate and 95% CI modelled with SARIMA (2,0,2) (2,1,0)[52] (red line with ribbon). **(Fourth row)** weekly mean age of children as a 13-week moving average, observed (grey line) and expected point estimate and 95% CI modelled with SARIMA (2,0,1) (2,1,0)[52] (red line with ribbon).

	Expected—SARIMA reference			Observed	Impact	
	13-week average point estimate	Low 95%	High 95%	13-week average	Ratio observed/expected	Percent change (%)
Incidence of hospitalizations per 100,000 children						
Winter 2020–2021	11.81	7.30	16.33	1.03	0.09	−91.25
Winter 2021–2022	11.63	6.89	16.37	8.74	0.75	−24.87
Winter 2022–2023	12.20	7.06	17.34	18.06	1.48	47.98
Winter 2023–2024	11.87	6.08	17.67	12.87	1.08	8.40
Incidence of PICU admissions per 100,000 children						
Winter 2020–2021	1.23	0.49	1.97	0.16	0.13	−86.93
Winter 2021–2022	1.29	0.46	2.13	1.16	0.90	−10.11
Winter 2022–2023	1.26	0.26	2.27	2.07	1.64	64.39
Winter 2023–2024	1.28	0.17	2.39	1.13	0.89	−11.31
Average percent PICU admissions (%)						
Winter 2020–2021	10.07	6.86	14.67	15.30	1.52	51.99
Winter 2021–2022	10.53	6.15	14.91	11.63	1.10	10.45
Winter 2022–2023	10.11	5.50	14.73	10.21	1.01	0.99
Winter 2023–2024	10.47	5.17	15.77	8.34	0.80	−20.33
Average age at discharge (months)						
Winter 2020–2021	34.29	27.30	41.27	56.41	1.65	64.52
Winter 2021–2022	34.16	26.57	41.75	31.68	0.93	−7.25
Winter 2022–2023	34.20	25.89	42.52	31.95	0.93	−6.61
Winter 2023–2024	34.21	24.86	43.57	35.14	1.03	2.69

[a]Winter seasons were defined as 13-week periods between December and February (i.e., start of week 49 to the end of week 9).

Table 2: **Impact of the COVID-19 pandemic on outcomes for all acute respiratory diseases among children less than 18 years old during winter seasons.**[a]

compared with the expected incidence 11.63 (95% CI 6.89, 16.37), thus near pre-pandemic incidence as predicted by the SARIMA model (Table 2; Fig. 2). However, a second unexpected peak was observed in spring and summer 2022 when most hospitalizations were for bronchiolitis (26.74%), asthma exacerbation (22.30%), and pneumonia (20.84%), followed by influenza (15.61%), COVID-19 (10.99%), and croup (3.52%) (Fig. 1).

By the late/post-pandemic period, mandatory non-pharmaceutical interventions were discontinued, and the stringency index fell below 10% during the autumn 2022 (Fig. 1). During the 2022–2023 winter season, the observed average weekly incidence of hospitalization for ARD per 100,000 children was 18.06 compared with the expected incidence 12.20 (95% CI 7.06, 17.34)—a 47.98% significant increase for ARD (Table 2; Fig. 2). Only the 82.65% increase in bronchiolitis was significant (Supplemental Table S1; Supplemental Fig. S1). The 14.89% increase in influenza-like illness, 24.57% increase in pneumonia, 51.04% decrease in croup, and 55.85% increase in asthma exacerbation were not significant (Supplemental Tables S2–S5; Supplemental Figs. S2–S5).

In winter 2023–2024, observed hospitalizations for ARD returned within the 95% CI of the expected incidence as predicted by the SARIMA model. The observed average weekly incidence of hospitalization for ARD per 100,000 children was 12.87 compared with the expected incidence 11.87 (95% CI 6.08, 17.67) (Table 2; Fig. 2). Hospitalizations for bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbation all returned near expected incidence (Supplemental Tables S1–S5; Supplemental Figs. S1–S5).

Impact of the COVID-19 pandemic on incidence and percent PICU admissions

Of the 52,839 hospitalizations for ARD, 4433 (8.39%) included a PICU admission (Table 1). During the pre-pandemic period, the incidence of ARD hospitalizations per 100,000 children had a stable biennial pattern, while the average weekly incidence of ARD PICU admissions significantly increased from 0.62 (95% CI 0.43, 0.80) in winter 2010–2011 to 1.30 (95% CI 1.00, 1.61) in winter 2016–2017 (Fig. 2). Concurrently, the average weekly percentage of PICU admissions doubled from 4.04% (95% CI 3.76, 4.32) in winter 2010–2011, to 8.84% (95% CI 8.53, 9.15) in winter 2016–2017 (Fig. 2). Thereafter, the weekly incidence and percent PICU admissions plateaued until winter 2019–2020 (Fig. 2).

During the pandemic period when few children were hospitalized and admitted to the PICU in winter 2020–2021, weekly percent PICU admissions appeared significantly increased (15.30% observed vs. 10.07% (95% CI 7.14, 13.00) expected) because hospitalizations were low (Table 2; Fig. 2). Thereafter, there was no significant difference in observed and expected percent PICU admissions during the 2021–2022, 2022–2023, and 2023–2024 winter seasons (Table 2; Fig. 2).

During the late/post-pandemic period in winter 2022–2023, the observed average weekly incidence of PICU admissions for ARD per 100,000 children was 2.07 compared with the expected incidence 1.26 (95% CI 0.26, 2.27)—a 64.39% increase for ARD though not significant (Table 2; Fig. 2). Only the 117.37% increase in bronchiolitis was significant (Supplemental Table S1; Supplemental Fig. S1).

Impact of the COVID-19 pandemic on average age at discharge

During the pre-pandemic period, mean age 13-week moving average had an annual seasonal pattern, where each winter the average age at discharge for ARD was 34.83 months (95% CI 33.66, 35.99) (Fig. 2). During the pandemic period when few children were hospitalized in winter 2020–2021, the observed average age was 56.41 months compared with the expected average age 34.29 (95% CI 27.30, 41.27)—a 64.52% significant increase (Table 2; Fig. 2). Thereafter, there was no

difference in the observed and expected average age during the 2021–2022, 2022–2023, and 2023–2024 winter seasons (Table 2; Fig. 2).

Discussion

This study describes seasonal hospitalizations and PICU admissions for all-cause ARD among all children across the province of Alberta, Canada, over 14 years from September 5, 2010, to August 31, 2024. The established patterns were dramatically disrupted during the COVID-19 pandemic, with significant declines in all ARD hospitalizations and PICU admissions during the pandemic period when society-wide non-pharmaceutical interventions were implemented from 2020 to 2022. Concurrently, amongst the few hospitalized children in winter 2020–2021, the percentage admitted to the PICU and their mean age appeared to transiently rise due to the low number of hospitalizations. Thereafter, the pattern of mean age remained stable. Each winter season the mean age decreased likely due to seasonal variation in pathogen exposures,[4] and age-related pathophysiology of ARD.[24]

This was followed by the late/post-pandemic period, when ARD hospitalization and PICU admissions significantly increased in winter 2022–2023, temporally associated with the withdrawal of non-pharmaceutical interventions. This rebound was not uniform for individual ARD. Only the incidence of hospitalizations and PICU admissions for bronchiolitis significantly increased by 82.65% and 117.37% respectively, above expected incidence and 95% CI predicted by SARIMA models. Hospitalizations for influenza-like illness, pneumonia, and asthma exacerbations increased above expected incidence but were not statistically significant. In contrast, hospitalizations for croup remained below expected incidence during winter seasons.

Hospitalizations and PICU admissions for all ARD returned to the expected seasonal pattern during winter 2023–2024 period compared with predictions by SARIMA models. These findings suggest that when considering all-cause ARD requiring hospitalization, any increase in individual or population-level susceptibility to common infectious pathogens, related to the COVID-19 pandemic and period of population-wide non-pharmaceutical interventions, may have largely resolved by the winter of 2023–2024.[6,27]

Few studies have reported on hospitalizations for common pediatric ARD using population-level data. A study by Pelletier et al. measured monthly general pediatric hospital and PICU admissions at 49 US hospitals from January 2010 to June 2020 and found a significant 45% reduction in the number of admissions in April 2020 for all diagnoses studied except birth.[31] Similarly, we found the weekly number and incidence of hospital and PICU admissions for pediatric ARD universally declined from March 2020 to September 2021, temporally related to more stringent non-pharmaceutical interventions. One other study by Izu et al. measured all-cause hospitalizations for lower respiratory tract infections among children in South Africa from January 2015, to December 2022.[32] This two-center study reported that the annual incidence of lower respiratory tract infections decreased by 30% in 2020, decreased by 13% in 2021, but increased by 16% in 2022 compared with the pre-pandemic period.[32] The difference in magnitude between our findings may be partly explained by variations in seasonal patterns of respiratory infectious diseases in northern and southern hemispheres.[3] Further, Izu et al. used less granular measures of annual incidence rather than weekly incidence averaged over 13-week seasons, perhaps dampening the effect size. Measuring weekly incidence to observe seasonal patterns of hospitalization affords additional detail to inform variation in health care resource use over one year.

Most studies measured pediatric hospitalizations for single infections or diseases, most notably for RSV infections or bronchiolitis.[7,9,11,27] Cong et al. summarized findings from 7 studies from high income regions and concluded that annual hospitalization rates of bronchiolitis decreased by 79% in 2020, started to increase in 2021, and returned to pre-pandemic levels by March 2022.[9] Similarly, we found that the seasonal incidence of hospitalization for bronchiolitis decreased by 96.47% in winter 2020–2021 and then remained within the expected 95% CI during winter 2021–2022 as predicted by the SARIMA model. However, conclusions by Cong et al. were premature as the epidemiology of ARD including bronchiolitis continued to evolve after 2022 when non-pharmaceutical interventions aimed at reducing SARS-CoV-2 transmission were discontinued in most jurisdictions.

More recent studies reported on the increase in pediatric RSV associated hospitalizations,[27,33] and bronchiolitis admissions up to 2023.[11,34] A single centre Canadian study from the British Columbia Children's Hospital with data until May 2023, and a multicentre US study including 32 pediatric hospitals until June 2023 observed 114% and 140% increases in the number of RSV associated hospitalizations respectively in 2022–2023 compared with the pre-pandemic period.[27,33] A second multicentre US study across 41 hospitals with data until June 2023 reported a 75% increase in the number of bronchiolitis admissions in 2022–2023 compared with the pre-pandemic period.[11] Similarly, we observed the seasonal incidence of hospitalization for bronchiolitis significantly increased by 82.65% in winter 2022–2023, and add that increases in hospitalization were also observed for influenza, pneumonia, and asthma exacerbation, though not significant.

Some studies suggested that the dramatic rise in RSV cases in later pandemic years can be attributed to

the increased detection, given that both RSV testing volumes and the average age of RSV cases increased in 2021–2023.[33] However, of the RSV cases admitted to hospital there was no change in average age.[33] Admissions to hospital are based on clinical symptoms and not viral testing results. Although our study did not include microbiologic testing data, the focus on ARD hospitalizations limited bias from variations in microbial testing practices,[15] and similarly found no change in the seasonal pattern of mean age amongst hospitalized children.

The longitudinal nature of our data captured an increasing trend in PICU admissions for ARD. During the pre-pandemic period while the incidence of ARD hospitalizations had a stable biennial pattern, the incidence and proportion of PICU admissions for ARD doubled between 2010 and 2017. Others have described a similar trend. A study across 38 US hospitals found that the proportion of children with bronchiolitis admitted to the PICU doubled from 11.7% in 2010 to 24.5% in 2019, and further described that increased use of non-invasive ventilation may be contributing to the increased proportion of PICU admissions, while invasive mechanical ventilation remained the unchanged.[35,36]

This study had numerous strengths. First, this is a population-level study of all hospitalizations for the most common ARD among the entire pediatric population in Alberta, Canada; including both tertiary children's hospitals and 95 other hospitals that admit children. Second, the study includes reported data up to August 31, 2024, well after the global peak of the COVID-19 pandemic and 2 years after discontinuation of society-wide non-pharmaceutical interventions. Third, the use of SARIMA modelling allowed us to compare the observed data during the COVID-19 pandemic and late/post-pandemic periods with expected results derived from 9.5 years of prior observations and considers seasonal variations such as biennial peaks of bronchiolitis. Fourth, this study reported on symptomatic cases of ARD requiring hospitalization, each caused or triggered by multiple viral and bacterial pathogens, with admission not dependent on microbial identification. Thus, our data avoided biases that could have resulted from changes in viral testing practices, as has been reported, particularly for RSV infections.[15,33]

This study also had some limitations. First, we did not obtain data on viral or bacterial testing thus discussing the etiology of confirmed clinical diagnoses is outside the scope of this work. Second, we did not include non-hospitalized children to examine milder cases of ARD, stratify children admitted to the PICU based on respiratory supports (i.e., heated high-flow nasal canula, non-invasive ventilation, or invasive mechanical ventilation) to further grade severe cases of ARD,[11] or characterise changes in respiratory supports over time.[35,36] Third, we did not stratify the analysis by sex,[34] age group,[34] ethnicity, or obtain data on confounders such as vaccination status which may have influenced some ARD trends. Continued study of seasonal patterns in ARD among children will improve understanding of longer-term trends after the COVID-19 pandemic. Inclusion of sex, comorbidities, health behaviours, social determinants of health, microbiologic testing data, and clinical diagnoses from non-hospitalized children will further broaden this understanding and improve awareness of annual seasonal respiratory illnesses in groups with particular risks and in the entire population. This can inform decisions about surge responses during future events that may disrupt the timing and magnitude of surges or declines in acute respiratory diseases.[8]

In summary, hospitalizations for the most common pediatric ARD—bronchiolitis, influenza-like illness, pneumonia, croup, and asthma exacerbation—each have unique seasonal patterns. During the pandemic period, these seasonal patterns were universally disrupted after the rise of SARS-CoV-2 infections and implementation of non-pharmaceutical interventions aimed at preventing SARS-CoV-2 transmission. During the late/post-pandemic period, after lifting mandatory non-pharmaceutical interventions, hospitalizations and PICU admissions for bronchiolitis, influenza-like illness, pneumonia, and asthma exacerbation, all exceeded expected levels predicted based on prior seasonal patterns. Only the increase in hospitalizations and PICU admissions for bronchiolitis was statistically significant. In contrast, hospitalizations for croup remained below expected levels. Further, there was no change to the pattern of mean age amongst hospitalized children suggesting no impacts on population and individual susceptibility to common infections symptomatic enough to require hospitalization.[6,27] These findings are generalizable to other jurisdictions in the northern hemisphere with universal health care that discontinued society-wide non-pharmaceutical interventions in 2022. Overall, the COVID-19 pandemic had significant impacts on the seasonal patterns of the most common pediatric ARD for multiple years but with evidence of return to pre-pandemic patterns by winter 2023–2024. Ongoing surveillance and predictions to describe the evolving seasonal pattern of ARD during the post-pandemic period will inform health system planning and delivery for both annual seasonal surges and future pandemics.[8]

Contributors

J.D.K. conceptualized the study. All authors contributed to development of the methodology. J.D.K. and C.D.L administered the study B.S. and C.D.L. accessed and verified the data. C.D.L. curated the data and conducted the formal analysis, including development of all software code used in the analysis. G.K. and J.H. provided consultation on epidemiology, statistics, and revised analysis code. All authors interpreted the results. J.D.K., C.D.L. and D.W.J. provided clinical expertise and context. J.D.K. and C.D.L. wrote the original draft of the manuscript and all revised versions. All authors reviewed and edited all versions of the manuscript, and all authors approved of the final version. This study was not analyzed, written, or edited by Artificial Intelligence.

Data sharing statement

In accordance with local regulations and assuming permission by the local Research Ethics Board, aggregated and anonymized Alberta hospital Discharge Abstract Data used in this study may be available upon request from data steward at Maternal and Child Data and Analytics, Alberta Health Services. Please email the corresponding author with inquiries.

Declaration of interests

C.D.L, B.S, G.P.S.K, J.K.H, and D.W.J. have no competing interests. J.D.K. has been an investigator on projects funded by Moderna Canada, Pfizer Canada, the Alberta Children's Hospital Research Institute and Government of Alberta, all outside the submitted work. All funds have been paid to his institute, and he has not received any personal payments. He has been an unpaid member of the Canadian COVID-19 Immunity Task Force Leadership Group and an unpaid member of the Alberta Advisory Committee on Immunization.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2025.101024.

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