

Trends in Bronchiolitis Hospitalizations in the United States: 2000–2016

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abstract

OBJECTIVES: To investigate the temporal trend in the national incidence of bronchiolitis hospitalizations, their characteristics, inpatient resource use, and hospital cost from 2000 through 2016.

METHODS: We performed a serial, cross-sectional analysis of nationally representative samples (the 2000, 2003, 2006, 2009, 2012, and 2016 Kids' Inpatient Databases) of children (age <2 years) hospitalized for bronchiolitis. We identified all children hospitalized with bronchiolitis by using *International Classification of Diseases, Ninth Revision, Clinical Modification* 466.1 and *International Classification of Diseases, 10th Revision, Clinical Modification* J21. Complex chronic conditions were defined by the pediatric complex chronic conditions classification by using inpatient data. The primary outcomes were the incidence of bronchiolitis hospitalizations, mechanical ventilation use, and hospital direct cost. We examined the trends accounting for sampling weights.

RESULTS: From 2000 to 2016, the incidence of bronchiolitis hospitalization decreased from 17.9 to 13.5 per 1000 person-years in US children (25% decrease; $P_{\text{trend}} < .001$). In contrast, the proportion of bronchiolitis hospitalizations among overall hospitalizations increased from 16% to 18% ($P_{\text{trend}} < .001$). There was an increase in the proportion of children with a complex chronic condition (6%–13%; 117% increase), hospitalization to children's hospital (15%–29%; 93% increase), and mechanical ventilation use (2%–5%; 184% increase; all $P_{\text{trend}} < .001$). Likewise, the hospital cost increased from \$449 million to \$734 million (63% increase) nationally (with an increase in geometric mean of cost per hospitalization [from \$3267 to \$4086; 25% increase; $P_{\text{trend}} < .001$] adjusted for inflation) from 2003 to 2016.

CONCLUSIONS: From 2000 through 2016, the incidence of bronchiolitis hospitalizations among US children declined. In contrast, mechanical ventilation use and nationwide hospital direct cost substantially increased.



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WHAT'S KNOWN ON THIS SUBJECT: During the previous decade, the incidence of bronchiolitis hospitalization significantly decreased in the United States.

WHAT THIS STUDY ADDS: During the current decade, bronchiolitis hospitalization incidence and mortality among US children continued to decline. By contrast, there were significant increases in the proportion of patients with pediatric complex chronic conditions, hospitalization to children's hospitals, mechanical ventilation use, and cost.

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Bronchiolitis is the most common lower respiratory tract infection among young children in the United States.¹ Almost all children are exposed to respiratory syncytial virus (RSV) and other causative pathogens (eg, rhinovirus) during the first 2 years of life.² Of these, ~40% of children develop clinical bronchiolitis and up to 3% are hospitalized.³ In 2009 alone, there were ~130 000 bronchiolitis hospitalizations (18% of infant hospitalizations), with a direct cost of \$550 million, in the United States.⁴

In the 2000s, the overall incidence of bronchiolitis hospitalization among US children decreased, whereas the use of mechanical ventilation and charge per hospitalization increased.⁴ Additionally, studies continued to report wide between-hospital variation in the inpatient bronchiolitis management.⁵⁻⁷ In this context, over the past 2 decades, there have been nationwide efforts to improve and standardize bronchiolitis diagnosis and management (such as the 2006 and 2014 American Academy of Pediatrics clinical practice guidelines for bronchiolitis).^{1,8} Despite the clinical and public health importance, the temporal trends in bronchiolitis hospitalizations among US children during the current decade remains uncertain.

To address this knowledge gap, we used a nationally representative sample of US children hospitalized with bronchiolitis to investigate the temporal trends in hospitalization incidence, their characteristics, mechanical ventilation use, and related cost from 2000 to 2016.

METHODS

Study Design and Setting

We performed a serial, cross-sectional analysis of a nationally representative sample of children hospitalized for bronchiolitis in 2000, 2003, 2006, 2009, 2012, and 2016

using the Healthcare Cost and Utilization Project's (HCUP) Kids' Inpatient Database (KID), compiled by the Agency for Healthcare Research and Quality. The KID is designed to make national estimates for hospital use and outcomes; it is the only all-payer inpatient care database for US children. The KID is a stratified sample of all pediatric hospitalizations from states that participate in the HCUP. The states provide discharge-level data on all hospitalizations from all nonfederal, short-term general and specialty hospitals in the state. The KID contains an 80% stratified sample of pediatric hospitalizations. In 2016, the KID contained the information for ~7 million weighted hospital discharges from 4200 hospitals across 46 states plus the District of Columbia. The details of the KID have been described elsewhere.⁹ The KID has been used to investigate the temporal trends in various conditions and validated against the National Hospital Discharge Survey.¹⁰⁻¹³ The Institutional Review Board of Massachusetts General Hospital approved this analysis.

Study Sample

We identified all children (age <2 years) hospitalized for bronchiolitis⁸ using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) code of 466.1 in the 2000–2012 data or *International Classification of Diseases, 10th Revision, Clinical Modification* (ICD-10-CM) codes of J21 in the 2016 data in the primary or secondary diagnosis fields on the basis of the approach used in previous studies.^{4,14-16} To minimize the potential misclassification with respiratory distress syndrome or transient tachypnea of the newborn, we excluded the hospitalizations for routine births identified using the Clinical

Classifications Software (CCS) code 218 in any fields.^{17,18}

Measurements

The KID contains the information on patient demographics (eg, age, sex, race and/or ethnicity), primary insurance (payer), hospitalization day (weekday or weekend), hospitalization diagnoses and procedures, hospital length of stay, disposition, and inpatient charge, as well as cost for hospitalization. Primary payer was grouped into public sources, private payers, and other types. Diagnoses and procedures were available by using the ICD-9-CM or ICD-10-CM, and CCS. CCS is a methodology developed by the Agency for Healthcare Research and Quality to group ICD-9-CM or ICD-10-CM codes into clinically sensible and mutually exclusive categories. Pediatric complex chronic conditions, consisting of 10 categories (cardiovascular, respiratory, neuromuscular, renal, gastrointestinal, hematologic or immunologic, metabolic, other congenital or genetic, malignancy, and neonatal), were defined by the pediatric complex chronic conditions classification system version 2¹⁹ on the basis of the inpatient diagnosis and procedure codes. Additionally, the KID also contains hospital characteristics, such as the US region (northeast, south, midwest, and west),²⁰ urban-rural status, teaching status,²⁰ and designation as a children's hospital.²⁰

Outcome Measures

The primary outcomes were the incidence of bronchiolitis hospitalization, use of invasive or noninvasive mechanical ventilation, and hospital direct cost. The secondary outcomes were length of stay and hospital mortality. The use of invasive and noninvasive mechanical ventilation was identified by ICD-9-CM and ICD-10-CM procedure codes

(Supplemental Table 3), according to previous studies.^{4,21} We computed the direct costs using the cost-to-charge ratios for the 2003–2016 hospitalizations (the cost-to-charge ratio was not available in 2000). The cost information was obtained from the hospital accounting reports collected by the Centers for Medicare and Medicaid Services.²² Data were reweighted to analyze the cost according to the HCUP recommendations.²³

Statistical Analysis

We investigated the temporal trends in the weighted estimates of outcomes in 2000, 2003, 2006, 2009, 2012, and 2016. To compute the incidence of bronchiolitis hospitalization, the annual number of estimated bronchiolitis hospitalizations was divided by the population estimate (eg, the number of general population aged <2 years) from the US Census Bureau.²⁴ To address a possibility that changes in diagnostic preference²⁵ and the transition from ICD-9-CM to ICD-10-CM explain the temporal trends in hospitalization incidence across the study years (ie, diagnostic substitution), we also examined the temporal trends for the hospitalization incidence for pneumonia (CCS code 122), other upper respiratory infections (CCS code 126), asthma (CCS code 128), other lower respiratory diseases (CCS code 133), and other upper respiratory diseases (CCS code 134) using the primary and secondary diagnosis fields. We used the Cochran-Armitage test, a statistical method that tests for a trend in binomial proportions (eg, bronchiolitis hospitalization: yes or no) across levels of an ordinal variable (eg, calendar years), to examine temporal trends for binary outcomes. Because the study objective was to examine the temporal trends (rather than the causal relationship between calendar

years and outcomes), we did not adjust for covariates. We also performed the nonparametric test, an extension of the Wilcoxon rank test,²⁶ to examine temporal trends for continuous outcomes. To facilitate direct comparisons of direct cost across the years, we converted all costs to 2016 US dollars using the Consumer Price Index.²⁷

We also conducted a series of sensitivity analyses to examine the temporal trends in different subpopulations. First, we repeated the primary analysis limited to infants (age <1 year). Second, we also repeated the analysis in the subgroups of children with bronchiolitis as the primary diagnosis. Third, we limited the analysis to children without complex chronic conditions. Fourth, we repeated the analysis in infants hospitalized with the primary diagnosis of bronchiolitis and without any complex chronic conditions. Finally, we limited the analysis to children with a complex chronic condition. We conducted the analyses using Stata 15.0 (Stata Corp, College Station, TX) and R version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria), with accounting for the complex sampling design to obtain proper variance estimations.

RESULTS

Bronchiolitis Hospitalization Incidence

There were 490 650 hospitalizations for bronchiolitis in the United States, corresponding to a weighted estimate of 775 858 hospitalizations in the 6 data sets (2000, 2003, 2006, 2009, 2012, and 2016). Overall, this accounted for 17% of all hospitalizations for children (age <2 years) and 18% for infants (age <1 year) after excluding all routine births.

From 2000 through 2016, there was a decrease in the incidence of bronchiolitis hospitalization from 17.9 (95% confidence [CI] 16.5–19.3) to 13.5 (95% CI 12.2–14.9) per 1000 person-years (25% decrease; $P_{\text{trend}} < .001$; Fig 1; Supplemental Fig 4). This downward trend was observed across all subpopulations ($P_{\text{trend}} < .001$) except for children with a complex chronic condition (70% increase; $P_{\text{trend}} < .001$). In parallel, the incidence of total hospitalizations declined (31% decrease; $P_{\text{trend}} < .001$) during the same period. Consequently, the annual proportion of bronchiolitis hospitalizations among the total hospitalizations for children increased (16% [95% CI 16%–17%] to 18% [95% CI 17%–19%]; 10% increase; $P_{\text{trend}} < .001$; Table 1).

To determine if diagnostic substitutions contributed to the trends, we also examined the trends in pneumonia, other upper respiratory infections, asthma, other lower respiratory diseases, and other upper respiratory diseases. From 2000 to 2016, the observed decline in bronchiolitis hospitalization incidence was mirrored by the concurrent decrease in hospitalization incidence for these diagnoses (all $P_{\text{trend}} < .001$; Supplemental Fig 5).

Patient and Hospital Characteristics

The patient and hospital characteristics of bronchiolitis hospitalization in the US children in the six 1-year periods are summarized in Table 1. Children hospitalized for bronchiolitis in more recent years were more likely to have a complex chronic condition (from 6% in 2000 to 13% in 2016; 117% increase; $P_{\text{trend}} < .001$). Additionally, there was a significant increase in the proportion of children hospitalized to an urban teaching hospital (48%–80%; 67% increase; $P_{\text{trend}} < .001$) and children's hospital

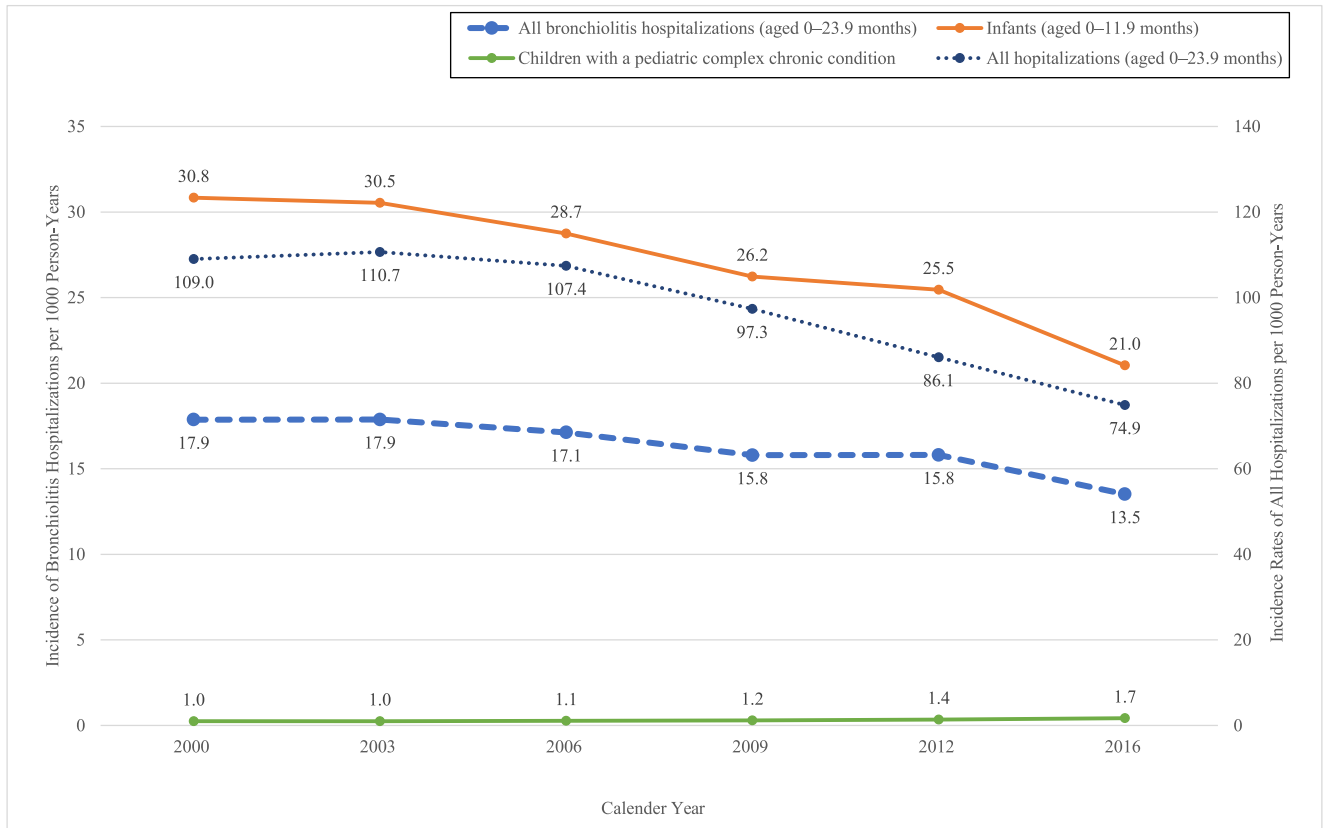


FIGURE 1

Incidence of bronchiolitis hospitalizations and all hospitalizations per 1000 children in the United States, 2000–2016. Overall, there was a significant decrease in the incidence of bronchiolitis hospitalization (25% decrease; $P_{\text{trend}} < .001$) and all hospitalizations (31% decrease; $P_{\text{trend}} < .001$) from 2000 through 2016. Likewise, there was a significant decrease in the incidence in infants (32% decrease; $P_{\text{trend}} < .001$). By contrast, there was a significant increase in children with complex chronic conditions (70% increase; $P_{\text{trend}} < .001$).

(15%–29%; 93% increase; $P_{\text{trend}} < .001$).

Mechanical Ventilation Use, Hospital Length of Stay, and Mortality

From 2000 to 2016, the proportion of children who underwent mechanical ventilation increased from 2% in 2000 to 5% in 2016 (184% increase; $P_{\text{trend}} < .001$; Fig 2). Although the upward trend was observed across the subpopulations (all $P_{\text{trend}} < .001$), children with a complex chronic condition had the highest mechanical ventilation use (12.7%) in 2016. Although the use of invasive mechanical ventilation modestly increased (35% increase), that of noninvasive mechanical ventilation substantially increased (1450% increase; both $P_{\text{trend}} < .001$; Fig 3).

During the same period, there was no clinically meaningful change in the hospital length of stay during the study period (Supplemental Table 4) except for the decrease among the patients with mechanical ventilation use (median: 10 days in 2000 to 7 days in 2016; $P_{\text{trend}} < .001$).

Over the study period, the hospital mortality for bronchiolitis modestly declined (0.06% [95% CI 0.04%–0.09%] to 0.05% [95% CI 0.03%–0.06%]; $P_{\text{trend}} = 0.02$; Supplemental Table 5). Although there was an apparent increase in the mortality between 2012 and 2016, the number of in-hospital deaths was relatively small in both years (31 and 50, respectively). Although the downward temporal

trend was observed across all subpopulations, it was more evident in the patients with mechanical ventilation use (2.3% [95% CI 1.4%–3.6%] to 0.5% [95% CI 0.3%–0.8%]; 78% decrease; $P_{\text{trend}} < .001$).

Hospital Cost

From 2003 to 2016, the geometric mean of direct cost per hospitalization increased from \$3267 (95% CI \$3188–\$3345) to \$4086 (95% CI \$3912–\$4260; 25% increase; $P_{\text{trend}} < .001$; Table 2). Furthermore, despite the decreased hospitalization incidence, the total cost for bronchiolitis hospitalization increased from \$449 million (95% CI \$421–\$478 million) to \$734 million (95% CI \$660–\$809 million) nationally, adjusted for

TABLE 1 Patient and Hospital Characteristics of Bronchiolitis Hospitalizations in the US Children, 2000–2016

	2000	2003	2006	2009	2012	2016	<i>P</i> _{trend} ^a
Age 0–23.9 mo							
Weighted No. bronchiolitis	136 757	141 436	137 236	127 634	125 142	107 653	—
Weighted No. total hospitalizations	834 618	876 894	862 018	787 833	681 520	596 664	—
Total hospitalizations, ^b %	16 (16–17)	16 (16–17)	16 (16–17)	16 (16–17)	18 (18–19)	18 (17–19)	<.001
Age 0–11.9 mo							
Weighted No. bronchiolitis	118 910	121 411	116 200	104 985	100 275	83 533	—
Weighted No. total hospitalizations	639 150	669 810	655 736	591 022	515 288	460 827	—
Total hospitalizations, ^c %	19 (18–19)	18 (18–19)	18 (17–18)	18 (17–18)	19 (19–20)	18 (17–19)	.003
RSV bronchiolitis, ^d %	9 (8–10)	9 (8–9)	9 (9–10)	9 (9–10)	11 (10–11)	10 (10–11)	<.001
Patient demographics							
Age							<.001
0–11.9 mo	87 (86–88)	86 (85–86)	85 (84–86)	82 (81–83)	80 (79–81)	78 (76–79)	
12–23.9 mo	13 (12–14)	14 (14–15)	15 (15–16)	18 (17–19)	20 (19–21)	22 (21–24)	
Male sex	59 (59–60)	59 (59–59)	58 (58–59)	59 (58–59)	58 (58–58)	58 (58–59)	<.001
Race and/or ethnicity							
Non-Hispanic white	42 (39–46)	34 (32–37)	35 (32–37)	39 (36–41)	43 (41–45)	42 (39–45)	<.001
Non-Hispanic African American	13 (12–15)	12 (11–13)	11 (10–12)	14 (12–16)	16 (14–17)	16 (14–18)	<.001
Hispanic	21 (19–24)	20 (18–23)	22 (19–25)	25 (22–27)	24 (22–27)	22 (20–25)	<.001
Other or unknown	23 (21–26)	34 (31–37)	32 (29–36)	23 (20–26)	17 (15–20)	20 (16–23)	<.001
Primary payer							
Public	53 (51–54)	57 (56–59)	60 (58–61)	63 (62–65)	65 (63–66)	63 (61–65)	<.001
Private	41 (39–43)	37 (35–38)	34 (32–36)	31 (30–33)	30 (29–31)	32 (30–34)	<.001
Other	6 (6–7)	6 (5–6)	6 (6–7)	6 (5–7)	5 (5–6)	5 (4–5)	<.001
Hospitalization day							<.001
Weekday ^e	78 (77–78)	77 (77–76)	77 (77–78)	77 (76–77)	76 (75–76)	75 (74–75)	
Weekend	22 (22–23)	23 (22–23)	23 (22–23)	23 (23–24)	24 (24–25)	25 (25–26)	
Any pediatric complex chronic conditions ^f	6 (5–6)	6 (5–6)	6 (6–7)	8 (7–8)	9 (8–9)	13 (12–13)	<.001
Cardiovascular conditions	2 (2–2)	2 (2–2)	2 (2–2)	2 (2–3)	3 (3–3)	4 (4–4)	<.001
Respiratory conditions	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–2)	2 (2–2)	<.001
Neurologic and neuromuscular conditions	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	<.001
Prematurity ^g	0.3(0.2–0.5)	0.3 (0.3–0.4)	0.4 (0.3–0.9)	1 (0.8–1)	1 (1–1)	2 (2–2)	<.001
Hospital characteristics							
Region							
Northeast	18 (15–22)	16 (14–18)	17 (15–20)	18 (15–22)	18 (14–22)	19 (15–24)	<.001
Midwest	18 (14–21)	22 (19–25)	23 (19–25)	20 (17–24)	22 (18–26)	22 (18–28)	<.001
South	40 (36–44)	42 (38–46)	40 (36–43)	40 (36–44)	39 (35–43)	35 (30–41)	<.001
West	24 (20–28)	20 (17–24)	20 (17–24)	22 (18–26)	22 (18–26)	23 (19–28)	.97
Location and teaching status							
Rural	20 (18–23)	20 (18–22)	16 (15–18)	16 (15–18)	12 (11–14)	7 (6–8)	<.001
Urban nonteaching	31 (28–34)	33 (30–36)	31 (28–34)	33 (29–36)	25 (22–28)	13 (11–15)	<.001
Urban teaching	48 (44–52)	47 (44–50)	52 (49–56)	51 (47–55)	63 (29–66)	80 (77–82)	<.001
Hospital designation							<.001
Non-children's hospital	85 (80–89)	85 (82–87)	83 (79–87)	81 (76–84)	78 (73–82)	71 (65–77)	
Children's hospital	15 (11–20)	15 (13–18)	17 (14–21)	19 (16–22)	22 (18–27)	29 (23–35)	

Data are expressed as % (95% confidence interval) unless otherwise indicated. —, not applicable.

^a *P* value for trend test.

^b Proportion of bronchiolitis hospitalizations among the total hospitalizations for children aged <2 y after excluding routine birth.

^c Proportion of bronchiolitis hospitalizations among the total hospitalizations for children aged <12 mo after excluding routine birth.

^d Identified by ICD-9-CM code of 466.11 and ICD-10-CM code of J21.0.

^e Hospitalization on Monday, Tuesday, Wednesday, Thursday, or Friday.

^f Ten pediatric complex chronic conditions were defined by the pediatric complex chronic conditions classification system version 2. Of these 10 categories, 3 major conditions are presented.

^g Defined by <37 wk of gestation or low birth weight (<2500 g), identified by ICD-9-CM code of 765.0, 765.0X, 765.1, 765.1X, or 765.21-28 and ICD-10-CM code of P07.0, P07.0X, P07.1, P07.1X, P07.2, P07.2X, P07.3, or P07.3X.

inflation (63% increase). This increase was driven largely by the increasing cost in patients with complex chronic conditions (\$36 million [95% CI \$33–\$40 million] to \$217 million [95% CI \$187–\$248

million]; 502% increase) and those who underwent invasive mechanical ventilation (\$77 million [95% CI \$59–\$95 million]–\$144 million [95% CI \$120–\$168 million]; 87% increase) in addition to the parallel increase

in the cost in patients without complex chronic conditions (25% increase) and those without mechanical ventilation use (23% increase). Additionally, the total direct cost for patients hospitalized for

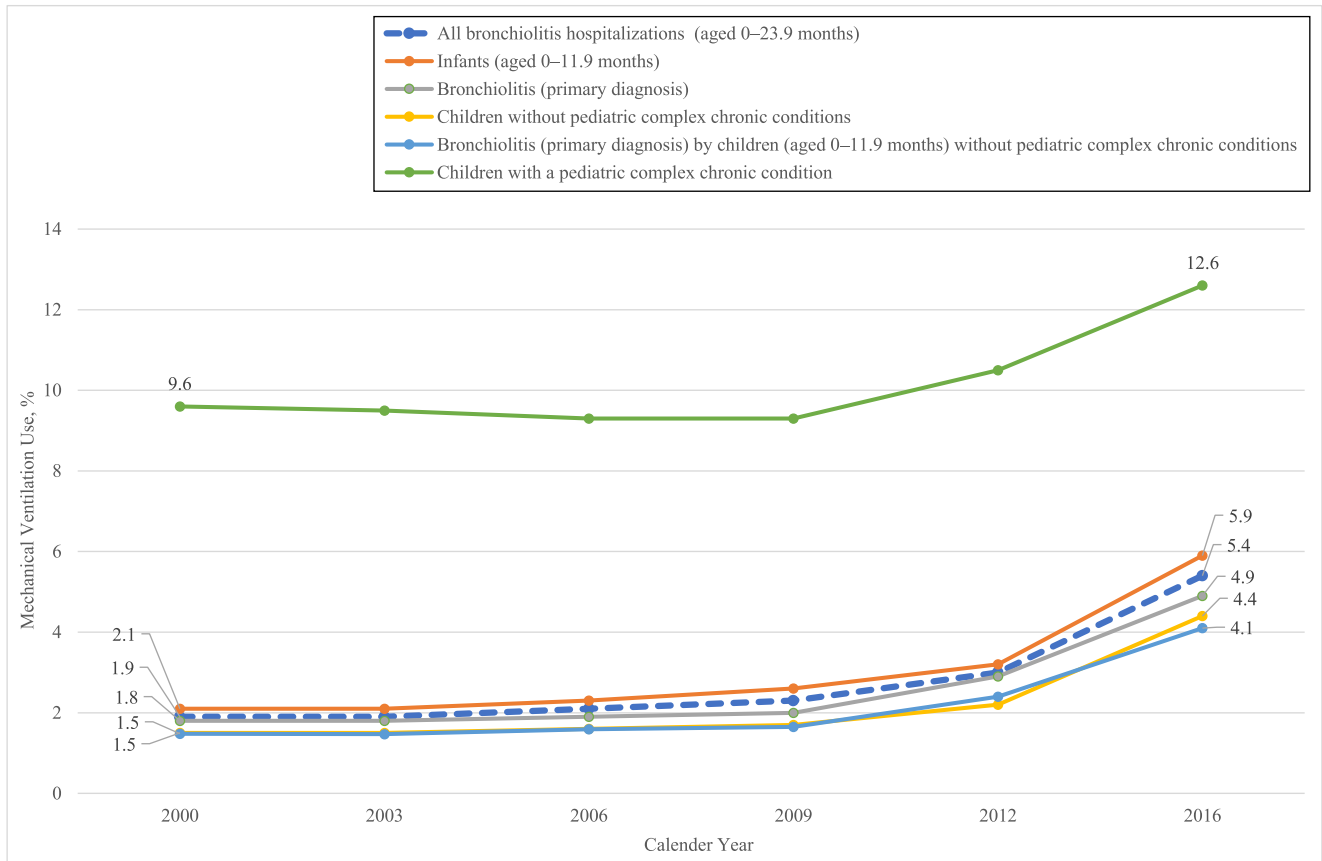


FIGURE 2

In-hospital mechanical ventilation use for US children with bronchiolitis according to different subpopulations, 2000–2016. Overall, the proportion of mechanical ventilation use in bronchiolitis hospitalizations increased from 2000 to 2016 (184% increase; $P_{\text{trend}} < .001$). Similarly, there was a significant increase in mechanical ventilation use across all different subpopulations (all $P_{\text{trend}} < .001$).

a children’s hospital also substantially increased (\$100 million [95% CI \$79–\$121 million] to \$329 million [95% CI \$264–\$394 million]; 229% increase).

DISCUSSION

Using nationally representative US data of hospitalized children during 2000 to 2016, we found significant decreases in the incidence of bronchiolitis hospitalizations, whereas its proportion among the overall hospitalizations increased. We also found that the in-hospital mortality for bronchiolitis declined during the 17-year period. In contrast, there was a substantial increase in the proportion of children with a complex chronic condition, hospitalizations to children’s

hospitals, use of mechanical ventilation (particularly in the use of noninvasive mechanical ventilation), and direct inpatient cost. Although these observations suggest a net improvement in clinical outcome of bronchiolitis, the inpatient resource use remains substantial (eg, ~108 000 hospitalizations with a direct cost of \$734 million) in 2016 alone.

Continued Decline in Bronchiolitis Hospitalization Incidence and Mortality

After the United States experienced a 2.4-fold increase in the incidence of bronchiolitis hospitalization through the 1980–1990s,²⁸ authors of a previous study reported a decrease in the incidence between 2000 and 2009.⁴ The current study extends

these earlier reports by demonstrating a sustained reduction in the incidence of bronchiolitis hospitalizations over the current decade, particularly in infants and children without complex chronic conditions. Interestingly, the proportion of bronchiolitis hospitalizations among the overall hospitalizations by children relatively increased from 16% to 18%. This finding is likely attributable to the observations (ie, bronchiolitis hospitalizations decreased at a slower rate than the overall hospitalizations), which suggest not only an overall improvement in pediatric care and health care use but also opportunities for improvement in bronchiolitis care. In parallel, the in-hospital mortality also declined. The reasons for the observed reductions

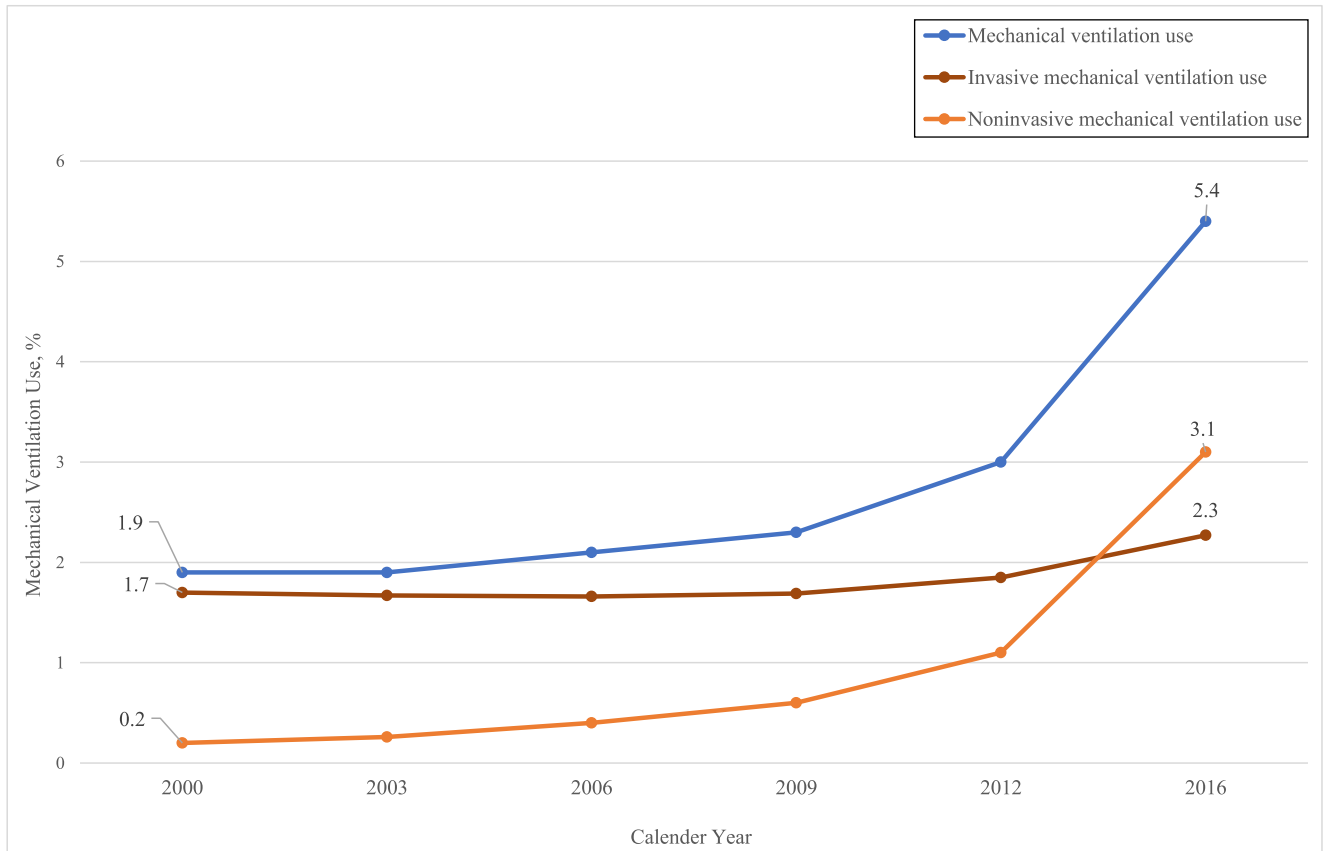


FIGURE 3

In-hospital invasive and noninvasive mechanical ventilation use for US children with bronchiolitis, 2000–2016. From 2000 to 2016, whereas the use of invasive mechanical ventilation modestly increased (34% increase; $P_{\text{trend}} < .001$), that of noninvasive mechanical ventilation substantially increased (1450% increase; $P_{\text{trend}} < .001$).

are likely multifactorial. For example, these findings may reflect reductions in disease incidences as well as improvement in prevention measures (eg, decrease in environmental tobacco smoke exposure).^{29,30} Alternatively, nonbiological factors, such as the continued efforts to optimize bronchiolitis care, including the dissemination of the 2006 and 2014 American Academy of Pediatrics guidelines for bronchiolitis diagnosis and management,^{1,8} may have contributed to the incremental improvement in clinical metrics and outcomes.³¹

In contrast, one might surmise that the observed temporal patterns are explained by potential

changes in diagnostic coding practice during the study period, particularly at the ICD-9-CM and ICD-10-CM transition period. However, we observed no compensatory increases in hospitalization incidence for other respiratory conditions with clinical manifestations similar to those of bronchiolitis (eg, pneumonia, other upper respiratory infections, asthma, other lower respiratory diseases, and other upper respiratory diseases). Instead, there were concurrent declines in their hospitalization incidences in addition to the decrease in the overall hospitalization incidence in the US children. Therefore, diagnostic substitution is unlikely to fully explain

the observed reduction in the incidence of bronchiolitis hospitalizations.

Increased Resource Use and Cost

The apparent reduction in the hospitalization incidence and mortality sharply contrasts with the upward trends in the proportion of children who were hospitalized in an urban teaching hospital and children's hospital as well as the use of mechanical ventilation. The etiologies for the observed increase remain to be elucidated. For example, the increase in the proportion of children with a complex chronic condition both in the general pediatric population^{32,33} and in children with bronchiolitis in more recent years might have

TABLE 2 Total Cost and Cost per Hospitalization for Bronchiolitis Hospitalization, According to Different Subpopulations, 2003–2016

	Cost					<i>P</i> _{trend} ^a
	2003	2006	2009	2012	2016	
All bronchiolitis hospitalizations, children aged						
0–23.9 mo						
Total direct cost (95% CI) ^b	449 (421–478)	735 (677–793)	641 (588–694)	701 (637–765)	734 (660–809)	.42
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3267 (3188–3345)	3624 (3509–3740)	3479 (3369–3589)	3523 (3378–3669)	4086 (3912–4260)	<.001
Sensitivity analyses						
Infants aged 0–11.9 mo						
Total direct cost (95% CI) ^b	381 (356–405)	639 (587–691)	547 (499–594)	583 (528–639)	599 (540–659)	.42
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3294 (3213–3376)	3696 (3574–3817)	3552 (3434–3670)	3594 (3440–3749)	4212 (4032–4392)	<.001
Bronchiolitis, primary diagnosis						
Total direct cost (95% CI) ^b	413 (386–439)	636 (585–687)	522 (476–568)	598 (543–652)	596 (534–658)	.58
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3235 (3156–3313)	3563 (3449–3676)	34.06 (3293–3518)	3470 (3324–3618)	3967 (3792–4141)	<.001
Children without pediatric complex chronic conditions						
Total direct cost (95% CI) ^b	413 (388–439)	613 (570–657)	515 (477–554)	542 (497–587)	517 (469–565)	.58
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3192 (3116–3278)	3465 (3360–3569)	3300 (3201–3398)	3305 (3176–3435)	3749 (3598–3899)	<.001
Bronchiolitis, primary diagnosis, by children aged						
0–11.9 mo without pediatric complex chronic conditions						
Total direct cost (95% CI) ^b	326 (305–347)	467 (433–502)	361 (331–391)	388 (355–422)	339 (308–371)	.90
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3195 (3116–3274)	3471 (3362–3579)	3296 (3189–3402)	3320 (3183–3458)	3724 (3572–3876)	<.001
Children with a pediatric complex chronic condition						
Total direct cost (95% CI) ^b	36 (33–40)	121 (104–139)	126 (108–144)	159 (149–180)	217 (187–248)	.046
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	5069 (4855–5284)	7055 (6634–7476)	6788 (6425–7151)	6871 (6473–7270)	7465 (7050–7880)	<.001
Stratification by use of mechanical ventilation						
With mechanical ventilation use						
Total direct cost (95% CI) ^b	94 (75–113)	114 (95–132)	117 (100–134)	141 (122–161)	195 (163–226)	.046
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	10 093 (9053–11 134)	25 212 (22 589–27 834)	25 618 (23 415–27 820)	21 445 (18 493–24 397)	18 525 (15 841–21 208)	<.001
Invasive mechanical ventilation use						
Total direct cost (95% CI) ^b	77 (59–95)	103 (85–120)	105 (90–121)	118 (101–135)	144 (120–168)	.046
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	10 376 (9301–11 450)	29 243 (26 311–32 174)	33 204 (30 390–36 019)	29 671 (23 068–36 275)	36 207 (33 191–39 223)	<.001
Noninvasive mechanical ventilation use						
Total direct cost (95% CI) ^b	17 (14–20)	11 (8–14)	12 (9–14)	23 (18–29)	51 (36–66)	.15
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	9090 (6587–11 594)	14 209 (12 737–15 681)	12 125 (11 082–13 168)	12 595 (11 541–13 648)	11 446 (10 101–12 792)	<.001
Without mechanical ventilation use						
Total direct cost (95% CI) ^b	440 (412–468)	621 (577–666)	524 (485–564)	560 (512–607)	539 (492–587)	.58
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3242 (3163–3320)	3478 (3373–3583)	3321 (3221–3420)	3337 (3204–3470)	3747 (3597–3897)	<.001
Stratification by hospital designation						
Non-children's hospital						
Total direct cost (95% CI) ^b	349 (329–370)	519 (482–556)	434 (404–465)	434 (399–469)	405 (367–444)	.97
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	3054 (2983–3125)	3304 (3208–3399)	3113 (3034–3193)	3060 (2952–3168)	3412 (3279–3544)	<.001
Children's hospital						
Total direct cost (95% CI) ^b	100 (79–121)	216 (170–262)	207 (162–251)	267 (213–322)	329 (264–394)	.07
Cost per hospitalization, geometric mean (95% CI) ^{c,d}	4696 (4421–4970)	5619 (5111–6127)	5883 (5406–6360)	5805 (5146–6464)	6506 (5924–7088)	<.001

^a *P* value for trend test. Cost was adjusted for inflation.

^b Data are presented as US dollars (million). Cost was adjusted for inflation.

^c Data are presented as US dollars. Cost was adjusted for inflation.

^d *P* value for trend test in unweighted samples because of the discontinuity in hospital identification codes between 2009 and 2012. Cost was adjusted for inflation.

contributed to the increased health care resource use. Indeed, this population is known to have a higher likelihood of hospitalization to a children's hospital and increased health care use.^{33,34} Consistently, the current study also revealed the highest mechanical ventilation use in children with a complex chronic condition during their bronchiolitis hospitalization. However, the absolute proportion of this population remained small (13% of total bronchiolitis hospitalization in 2016). Alternatively, it is also possible that these patterns reflect an improvement in the coordination of care through regional care systems for critically ill (similar to neonatal intensive care systems³⁵) and more liberal use of mechanical ventilation (particularly noninvasive mechanical ventilation), thereby contributing to the decreases in mortality. Furthermore, these mechanisms are not mutually exclusive.

Parallel to the increased hospital resource use, we also observed a 63% increase in the nationwide direct cost from 2003 to 2016, despite the overall decline in the bronchiolitis hospitalization incidence with a relatively stable hospital length of stay. Whereas the cost per hospitalization significantly increased in all subpopulations during the 17-year period, the increased nationwide cost for bronchiolitis hospitalizations was largely attributable to the increased cost in children with complex chronic conditions as well as critically ill children who underwent mechanical ventilation. The population with complex chronic conditions is known to have more intensive resource use (including noninvasive and invasive respiratory support) during hospitalizations, thereby leading to a higher hospital cost.^{4,33} Additionally, we also observed the

increase in cost in children without complex chronic conditions or mechanical ventilation use, suggesting that the observed increase in the nationwide cost for bronchiolitis is also attributable to the well-documented role of physician and hospital service fees in the increasing cost.³⁶ Furthermore, the literature has continued to report inconsistencies between clinicians as to the best bronchiolitis management, which is demonstrated by the wide variability in diagnosis and care in this population.⁵⁻⁷ This mechanism might also have attributed, at least partially, to the observed increases in health care use and hospital cost.

The observed reduction in hospitalization incidence and mortality supports a cautious optimism that the bronchiolitis morbidities can be further reduced. Yet, the health care use and cost in children hospitalized for bronchiolitis in the United States remains substantial in 2016. The identification of these temporal trends should not only motivate future studies into the determinants of the rising use and cost but also encourage renewed efforts to develop better systems of care that achieve high-quality, cost-effective care in this large population of sick children.

Potential Limitations

This study has several potential limitations. First, because of the use of administrative data, there are potential errors in recording diagnoses resulting in under- or overestimation of the incidence of bronchiolitis hospitalizations. Similarly, the transition from the ICD-9-CM to ICD-10-CM may have caused a discontinuity in the trends over the study period. However, our sensitivity analysis revealed similar downward trends in the hospitalization incidence

for potentially misclassified diagnoses and conditions. Therefore, it is unlikely that misclassifications and diagnostic substitutions have fully explained the observed temporal trends. Second, the data availability of the KID precluded us from evaluating potential annual variations in RSV and other respiratory viruses. Yet, the observed trends revealed consistent trends (eg, the consistent decrease in the incidence of bronchiolitis hospitalizations) rather than year-by-year fluctuations. Additionally, the prevalence of RSV bronchiolitis was likely to be underestimated in the current study. This research question is better examined by active surveillance or high-quality prospective studies of children with severe bronchiolitis. Third, the KID contains hospital discharge-level records (ie, not patient-level records). Thus, we were unable to assess repeat health care use outcomes (eg, rehospitalizations). Although a small proportion of children might have been readmitted in the same calendar year, the number of mortality outcomes does not change. Fourth, the KID does not contain some helpful clinical and environmental information (eg, palivizumab use and household smoking exposure). Our study had an objective to investigate the nationwide trends in health care use and outcomes and should facilitate further investigations into the possible mechanisms that explain our findings. Similarly, the KID samples consisted of hospitalizations, and they were thus unable to evaluate temporal changes in insurance composition of the nation. Lastly, although the study data consisted of a nationally representative sample, we must generalize our inferences cautiously beyond children hospitalized with bronchiolitis (eg, those with bronchiolitis in ambulatory settings). Nonetheless, our data

remain directly relevant to >100 000 children hospitalized (and their families) yearly in the United States. These children are precisely the population for which effective preventive and therapeutic strategies are most urgently needed.³

CONCLUSIONS

On the basis of the analysis of nationally representative US data of children hospitalized for bronchiolitis during 2000 to 2016, we found downward trends in the overall incidence of bronchiolitis hospitalization and hospital mortality. By contrast, we also observed substantial increases in the

proportion of children with a complex chronic condition, hospitalizations to a children's hospital, use of mechanical ventilation, and direct inpatient cost. For clinicians and researchers, our observations underscore the importance of continued efforts to develop effective prevention, treatment, and prognostication strategies for bronchiolitis, particularly in infants at high risk for severe bronchiolitis, which will, in turn, not only lead to additional improvement in the patient outcomes but also curb the rising hospital costs.

ABBREVIATIONS

CCS: Clinical Classifications Software

CI: confidence interval

HCUP: Healthcare Cost and Utilization Project

ICD-9-CM: *International Classification of Diseases, Ninth Revision, Clinical Modification*

ICD-10-CM: *International Classification of Diseases, 10th Revision, Clinical Modification*

KID: Kids' Inpatient Database

RSV: respiratory syncytial virus

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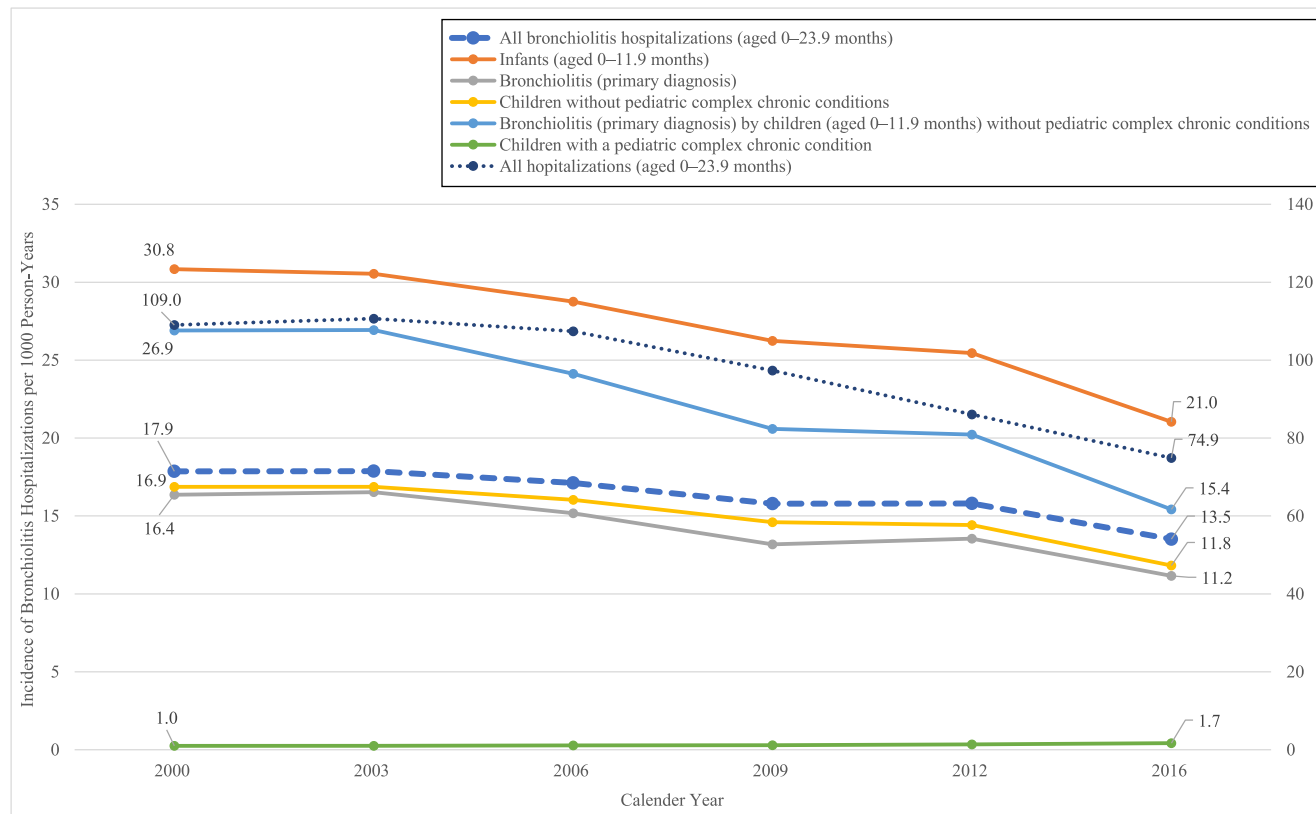
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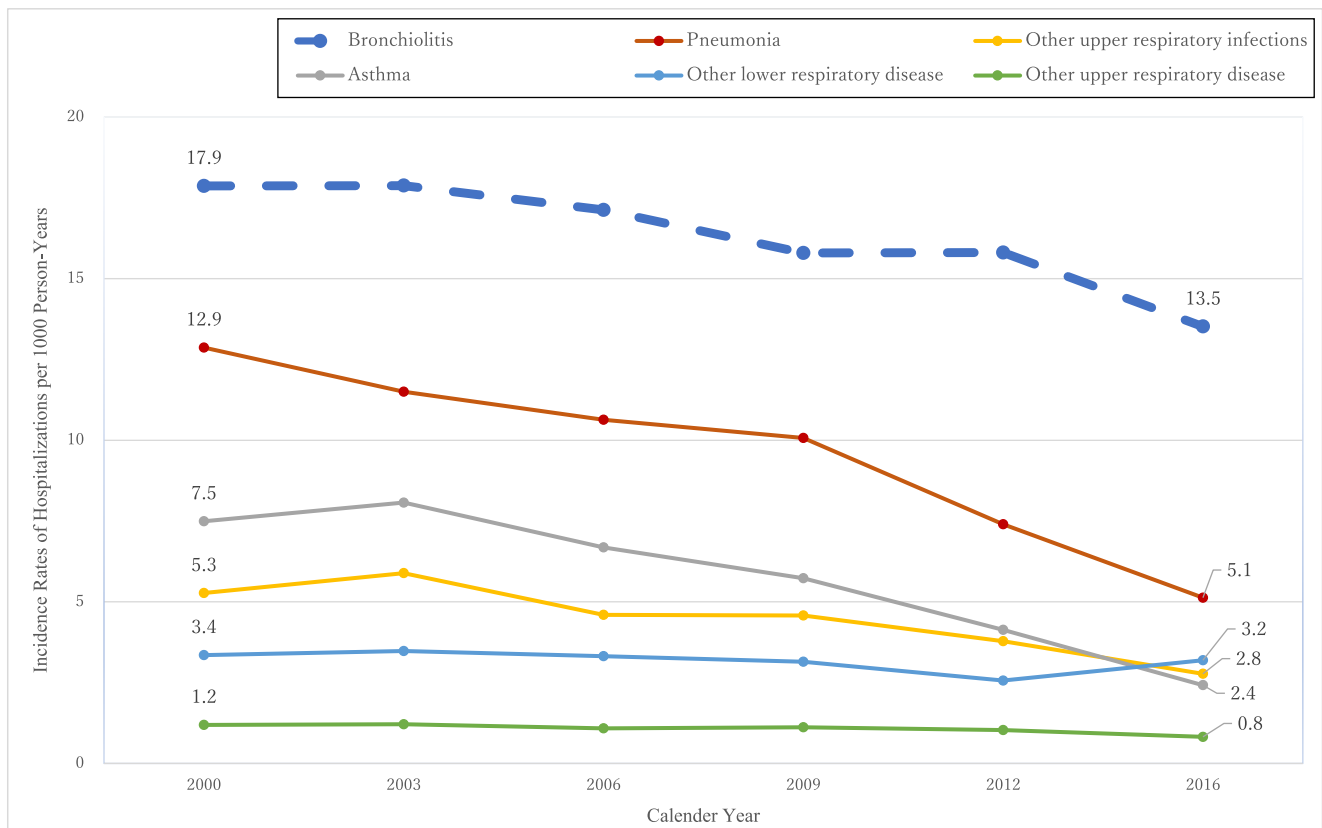
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Supplemental Information



SUPPLEMENTAL FIGURE 4

Incidence of bronchiolitis hospitalizations and all hospitalizations per 1000 children in the United States, 2000–2016. Overall, there was a significant decrease in the incidence of bronchiolitis hospitalization (25% decrease; $P_{\text{trend}} < .001$) and all hospitalizations (31% decrease; $P_{\text{trend}} < .001$) from 2000 through 2016. Likewise, there was a significant decrease in the incidence in different subpopulations, except for children with complex chronic conditions (70% increase; $P_{\text{trend}} < .001$).



SUPPLEMENTAL FIGURE 5

Incidence of hospitalizations for bronchiolitis, pneumonia, other upper respiratory infections, asthma, other lower respiratory diseases, and other upper respiratory diseases per 1000 children in the United States, 2000–2016. We identified children aged <2 years hospitalized for a diagnosis with pneumonia (CCS code 122), other upper respiratory infections (CCS code 126), asthma (CCS code 128), other lower respiratory diseases (CCS code 133), and other upper respiratory diseases (CCS code 134). Across the diagnoses, there was a consistent downward trend in the incidence of hospitalization (all $P_{\text{trend}} < .001$).

SUPPLEMENTAL TABLE 3 Variables and Corresponding ICD-9-CM and ICD-10-CM Codes

Variables	ICD-9-CM Code	ICD-10-CM Code
Acute bronchiolitis due to RSV	466.11	J21.0
Prematurity (<37 wk' gestation) or low birth wt	765.0, 765.0X, 765.1, 765.1X, 765.21-28	P07.0, P07.0X, P07.1, P07.1X, P07.2, P07.2X, P07.3, P07.3X
Invasive mechanical ventilation	93.01, 96.03, 96.04, 96.05, 96.70, 96.71, 96.72	ODH57BZ, ODH58BZ, OBH17EZ, OBH18EZ, OB717DZ, OB718DZ, OBH07DZ, OWHQ7YZ, 5A1935Z, 5A1945Z, 5A1955Z
Noninvasive mechanical ventilation	93.90, 93.91	5A09357, 5A09457, 5A09557, 5A09358, 5A09458, 5A09558

SUPPLEMENTAL TABLE 4 Length of Stay for Bronchiolitis Hospitalization, According to Different Subpopulations, 2000–2016

	Hospital Length of Stay in d, Median (IQR) ^a						<i>P</i> _{trend} ^b
	2000	2003	2006	2009	2012	2016	
All bronchiolitis hospitalizations, children aged 0–23.9 mo	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	<.001
Sensitivity analyses							
Infants aged 0–11.9 mo	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	.96
Bronchiolitis, primary diagnosis	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (1–4)	2 (1–4)	<.001
Children without pediatric complex chronic conditions	2 (2–4)	2 (2–4)	2 (2–3)	2 (2–3)	2 (1–3)	2 (1–4)	<.001
Bronchiolitis, primary diagnosis, by children aged 0–11.9 mo without pediatric complex chronic conditions	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	<.001
Children with a pediatric complex chronic condition	4 (2–7)	4 (2–7)	4 (2–7)	4 (2–7)	4 (2–7)	4 (2–7)	.001
Stratification by use of mechanical ventilation							
With mechanical ventilation use	10 (6–15)	10 (6–16)	10 (5–15)	10 (6–15)	8 (4–14)	7 (4–12)	<.001
Without mechanical ventilation use	2 (2–4)	2 (2–4)	2 (2–4)	2 (2–4)	2 (1–4)	2 (1–4)	<.001

IQR, interquartile range.

^a Median was calculated in weighted samples.^b *P* value for trend test in unweighted samples because of the discontinuity in hospital identification codes between 2009 and 2012.**SUPPLEMENTAL TABLE 5** In-Hospital Mortality for Bronchiolitis According to Different Subpopulations, 2000–2016

	In-Hospital Deaths ^a						<i>P</i> _{trend}
	2000	2003	2006	2009	2012	2016	
All bronchiolitis hospitalizations, children aged 0–23.9 mo, % (95% CI)	0.06 (0.04–0.09)	0.04 (0.03–0.06)	0.04 (0.03–0.06)	0.03 (0.02–0.05)	0.02 (0.02–0.04)	0.05 (0.03–0.06)	.02
Weighted No. deaths, <i>n</i> (95% CI)	77 (42–112)	59 (38–80)	55 (33–76)	42 (25–59)	31 (17–45)	50 (34–67)	
Sensitivity analyses, % (95% CI)							
Infants aged 0–11.9 mo	0.05 (0.03–0.09)	0.04 (0.03–0.06)	0.04 (0.02–0.06)	0.03 (0.02–0.05)	0.02 (0.01–0.04)	0.04 (0.03–0.06)	.01
Bronchiolitis, primary diagnosis	0.06 (0.04–0.09)	0.04 (0.02–0.05)	0.04 (0.03–0.06)	0.03 (0.02–0.04)	0.02 (0.02–0.04)	0.04 (0.03–0.06)	.01
Children without pediatric complex chronic conditions	0.02 (0.01–0.05)	0.005 (0.002–0.01)	0.006 (0.003–0.02)	0.008 (0.004–0.02)	0.001 (0.0002–0.009)	0.008 (0.0003–0.02)	<.001
Bronchiolitis, primary diagnosis, by children aged 0–11.9 mo without pediatric complex chronic conditions	0.02 (0.01–0.06)	0.005 (0.002–0.01)	0.005 (0.002–0.02)	0.006 (0.002–0.02)	0.002 (0.0003–0.01)	0.005 (0.001–0.02)	<.001
Children with a pediatric complex chronic condition	0.7 (0.4–1.0)	0.7 (0.5–0.9)	0.5 (0.4–0.8)	0.3 (0.2–0.5)	0.3 (0.2–0.4)	0.3 (0.2–0.5)	<.001
Stratification by use of mechanical ventilation							
With mechanical ventilation use	2.3 (1.4–3.6)	1.7 (1.1–2.5)	1.6 (1.1–2.4)	1.3 (0.8–1.9)	0.7 (0.5–1.1)	0.5 (0.3–0.8)	<.001
Without mechanical ventilation use	0.01 (0.006–0.03)	0.009 (0.005–0.02)	0.007 (0.002–0.02)	0.004 (0.001–0.01)	0.003 (0.001–0.01)	0.02 (0.001–0.03)	.68

^a Mortality was calculated in weighted samples. The number of deaths in each stratum was not presented according to the HCUP's Data Use Agreement.