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Pertussis Hospitalizations Among Infants in the United States, 1993 to 2004

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What's Known on This Subject

Incidence rates of reported infant pertussis among infants ≤ 4 months of age and reported infant pertussis deaths increased from the 1980s to the 1990s, according to national passive surveillance data, despite a fully implemented vaccination program.

What This Study Adds

Recent data on the incidence of pertussis hospitalization among infants in the United States from national discharge databases are presented; rates were generally stable among the youngest infants and were 2 times higher than those estimated from the passive system. Infants 1 to 2 months of age had the highest rates.

ABSTRACT

OBJECTIVE. We sought to describe the rates of pertussis hospitalization among infants by using databases that do not rely on passive reporting and compare with results obtained from the passive national surveillance system.

METHODS. The incidence of infant pertussis hospitalization in 1993 to 2004 was determined by using 2 national hospitalization discharge databases (Nationwide Inpatient Sample and Kids' Inpatient Database) and the National Notifiable Disease Surveillance System/Supplemental Pertussis Surveillance System. Rates were determined for separate age groups among infants < 1 year of age. Pertussis complications and procedures were examined by using the Kids' Inpatient Database.

RESULTS. In 1993 to 2004, the pertussis hospitalization rates for infants ≤ 2 months of age were generally stable, by the discharge databases. The incidence of infant pertussis hospitalization obtained from the Nationwide Inpatient Sample and Kids' Inpatient Database was ~ 2 times greater than that obtained from the passive reporting system. Infants 1 to 2 months of age had the highest incidence (239 hospitalizations per 100 000 live births in the 2003 Kids' Inpatient Database). An annual average of 2678 hospitalizations occurred in 2000 and 2003; 86% occurred in infants ≤ 3 months of age. Among those with ages provided, 95% of infants who required mechanical ventilation and all of those who died were ≤ 3 months of age.

CONCLUSIONS. Pertussis hospitalization incidence rates among the youngest infants were generally stable in 1993 to 2004 and were highest for infants 1 to 2 months of age. The impact of the new adolescent and adult tetanus-diphtheria-acellular pertussis vaccines on infant pertussis should be monitored through such discharge databases. Additional vaccination strategies should be evaluated to protect infants as early in life as possible.

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Key Words

pertussis, whooping cough, infants, immunization, hospitalization, surveillance

Abbreviations

DTaP—diphtheria/tetanus/acellular pertussis
 KID—Kids' Inpatient Database
 NIS—Nationwide Inpatient Sample
 RSV—respiratory syncytial virus
 SPSS—Supplemental Pertussis Surveillance System
 CI—confidence interval

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IN THE PREVACCINE era, pertussis was one of the major childhood illnesses, from which almost no child escaped, and was a leading cause of child death. With the institution of pertussis vaccination in the United States in the 1940s, pertussis morbidity and mortality rates decreased dramatically.^{1,2} Over time, the childhood vaccination program reached increasingly more children; from 1994 onward, $\geq 90\%$ coverage for ≥ 3 doses of pertussis-containing vaccine was achieved among children 19 to 35 months of age.³ Despite full implementation of the vaccination program, however, an increase in pertussis cases among infants ≤ 4 months of age reported to the national passive surveillance system was observed between the 1980s and the 1990s.² This increase in reported cases

TABLE 1 Proportion of Infants Reported With Pertussis With Unknown Hospitalization Status and Proportion Hospitalized According to Age Group and Time Period, From SPSS

Age at Cough Onset	Annual Proportion of Infants With Unknown Hospitalization Status, Median (Range), % ^a		Annual Proportion of Infants Hospitalized, 1993–2004, Median (Range), % ^b
	1993–1999	2000–2004	
0 mo	2 (0–8)	13 (7–22)	84 (79–88)
1–2 mo	1 (0–8)	16 (9–27)	74 (72–77)
3–4 mo	2 (0–11)	21 (13–31)	53 (41–61)
5–6 mo	2 (1–12)	26 (13–29)	40 (28–61)
7–11 mo	2 (0–13)	28 (11–32)	30 (14–43)
Total <1 y	2 (1–9)	19 (10–27)	65 (59–67)

^a Of total pertussis cases reported.

^b Of pertussis cases with hospitalization status reported; excludes cases with hospitalization status unknown or missing.

was accompanied by an increase in reported infant pertussis deaths, which suggested that the overall burden of pertussis among young infants had increased.⁴

These patterns of reported pertussis were based on the national passive surveillance system, which consists of the National Notifiable Disease Surveillance System and the Supplemental Pertussis Surveillance System (SPSS).² State health departments voluntarily report pertussis cases to the national system. Local health departments, laboratories, clinicians, and other health care personnel report cases to the state health departments, following state laws and regulations.⁵ Because such passive systems rely on reporting and reporting practices can change over time, trends observed with passive surveillance data are difficult to interpret. Therefore, we used nationally representative hospitalization discharge databases to describe the incidence of pertussis hospitalization among specific age groups of infants 0 to 11 months of age in 1993 to 2004, and we compared the results with the passive data. We also used the discharge databases to examine complications and procedures for infants hospitalized with pertussis.

METHODS

Birth Data

Data on live births were obtained from the National Center for Health Statistics.^{6,7} To estimate the number of live births in each 1-month age cohort, the number of live births reported for each calendar year was divided by 12. Rates of pertussis hospitalizations per 100 000 live births were estimated for infants <1 year of age and for various age groups. Single-month ages were combined on the basis of similarity of rates and the US schedule of infant pertussis immunization (doses at 2, 4, and 6 months of age).⁸ Gender-specific live births^{6,9} were used as denominators for gender-specific pertussis rates. Annual incidence rates of pertussis hospitalizations among infants were derived from 3 databases, that is, the national SPSS and 2 nationally representative hospital discharge databases, the Nationwide Inpatient Sample (NIS) and the Kids' Inpatient Database (KID).

SPSS

The SPSS is a supplement to the National Notifiable Disease Surveillance System, through which cases of

notifiable diseases are reported to the Centers for Disease Control and Prevention. Additional detailed information on reported pertussis cases (eg, age at cough onset [in months] and hospitalization status) is also collected. Before 1996, SPSS data were submitted on surveillance worksheets from state health departments to the Centers for Disease Control and Prevention; beginning in 1996, SPSS information was able to be transmitted via the National Electronic Telecommunication Surveillance System.² Pertussis cases reported by the 50 states and the District of Columbia as confirmed or probable¹⁰ were used in this analysis.

In the SPSS, age is defined as the age at cough onset and no information on age at hospital admission is available. Hospitalization status was missing/unknown for some infants in the SPSS (Table 1). The proportion of infant cases with missing hospitalization status increased from 2% in 1993 to 27% in 2004. For 2002 to 2004, hospitalization status was missing for all cases in 5 to 7 states, and those states contributed 27% to 58% of all cases with missing status. A proportion of all cases with missing status were assumed to be hospitalized, and this proportion was determined through an imputation procedure. Hospitalization status (yes, no, or unknown) was stratified according to year and age group. Within each stratum, the proportion of infants who were hospitalized among infants with known status was then applied to infants with missing status, to estimate the number who were hospitalized but not reported as hospitalized.

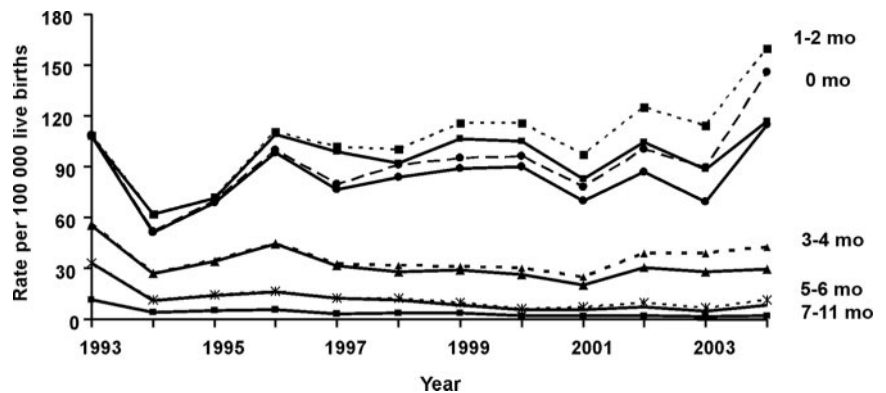
NIS

The NIS and the KID are both part of the Healthcare Cost and Utilization Project, established by the Agency for Healthcare Research and Quality.¹¹ National estimates derived from these sources were weighted to represent the 50 states, the District of Columbia, Puerto Rico, and the US territories combined and were calculated by following Healthcare Cost and Utilization Project recommended weighting procedures, using the SAS Surveymeans procedure.¹²

The NIS is a nationally representative database of hospital inpatient stays that is published annually and contains information on ~5 million to ~8 million inpatient stays (discharges) for patients of all ages.^{13,14} The NIS is a stratified probability sample of US hospitals. The

FIGURE 1

Incidence of reported pertussis hospitalization among infants according to age group in the SPSS (1993–2004). Solid lines indicate reported hospitalized only; dashed lines, reported hospitalized and imputed.



number of states contributing to the NIS has increased over time (eg, 8–11 states before 1993, 17 states in 1993, and 37 states in 2004); because of concerns about coverage, the Agency for Healthcare Research and Quality recommends that trend analyses begin with the year 1993.¹⁵ Therefore, we began our study period with 1993. Up to 15 diagnoses and 15 procedures can be included per hospitalization. For the primary analysis, infant pertussis hospitalizations were selected by searching all International Classification of Diseases, Ninth Revision, Clinical Modification discharge diagnosis codes among infants <1 year of age for 2 codes in category 033 (whooping cough [includes pertussis]), namely, 033.0 (*Bordetella pertussis*) and 033.9 (whooping cough, unspecified organism). The age in months at hospital admission was calculated by using the age in days at admission divided by 30.4375. For cases from states where the age in days was not provided but the age in months was provided, the age in months was used as provided. A few states (eg, 5 states in 2003 and 2004) reported age at admission only in years and neither age in days nor age in months was available. To include all infant pertussis hospitalizations in the age group analyses, cases with age reported only as 0 years were weighted by using the standard NIS weighting procedure to give the national estimate of the number of such cases for that calendar year. We then distributed the cases in single-month age categories, following the weighted distribution of pertussis cases for which the age in months was available. The median proportion of weighted pertussis cases for which the age in months was imputed was 13.5% (range: 0%–29%) for 1993 to 2004. Confidence intervals (CIs) (95%) were calculated for the NIS rates on the basis of only nonimputed data, by using recommended weighting procedures.

KID

The KID is a nationally representative database of pediatric inpatient stays that contains information on 2 million to 3 million inpatient discharges among children from ~3000 hospitals in states participating in the Healthcare Cost and Utilization Project.^{16,17} KID data were available for 1997 (22 participating states), 2000 (27 states), and 2003 (36 states). The primary analysis was performed as described for the NIS. Five states in

2000 and 4 states in 2003 reported age at admission in years only. The proportions of weighted pertussis cases for which we imputed the age in months were 12% in 1997, 22% in 2000, and 23% in 2003. National estimates of the numbers (and 95% CIs) of pertussis hospitalizations were obtained by following recommended weighting procedures.

For the 2 most-recent KID sampling years (2000 and 2003), all additional diagnosis codes for infants with pertussis were reviewed for known pertussis complications (eg, pneumonia) and possible underlying health conditions (eg, congenital heart disease); procedure codes were also reviewed for expected procedures (eg, mechanical ventilation and extracorporeal membrane oxygenation) (Appendix). Proportions with complications/procedures were estimated on the basis of weighted numbers.

RESULTS

Incidence Rates of Pertussis Hospitalization

SPSS

In the SPSS, the proportion of infants with pertussis who were hospitalized was highest among infants 0 months of age (84%) and decreased with increasing age (Table 1). Infants 1 to 2 months of age had the highest incidence of pertussis hospitalization (Fig 1), followed by infants 0 months of age. Imputation of hospitalization status for infants without reported status (Table 1) modestly increased rates of pertussis hospitalizations for each year (Fig 1) and suggested an increase in incidence over the study period among infants ≤ 2 months of age (Fig 1).

NIS and KID

Pertussis hospitalization rates derived from the NIS were generally stable from 1993 through 2004 for infants ≤ 2 months of age (Fig 2). Rates for infants 3 to 11 months of age seemed to decrease. The findings were similar across the 3 years for which data were available from the KID. The rank order of rates according to age group was the same as in the SPSS, with infants 1 to 2 months of age having the highest rates. Including infants with imputed values for age in months, peak rates in the NIS for

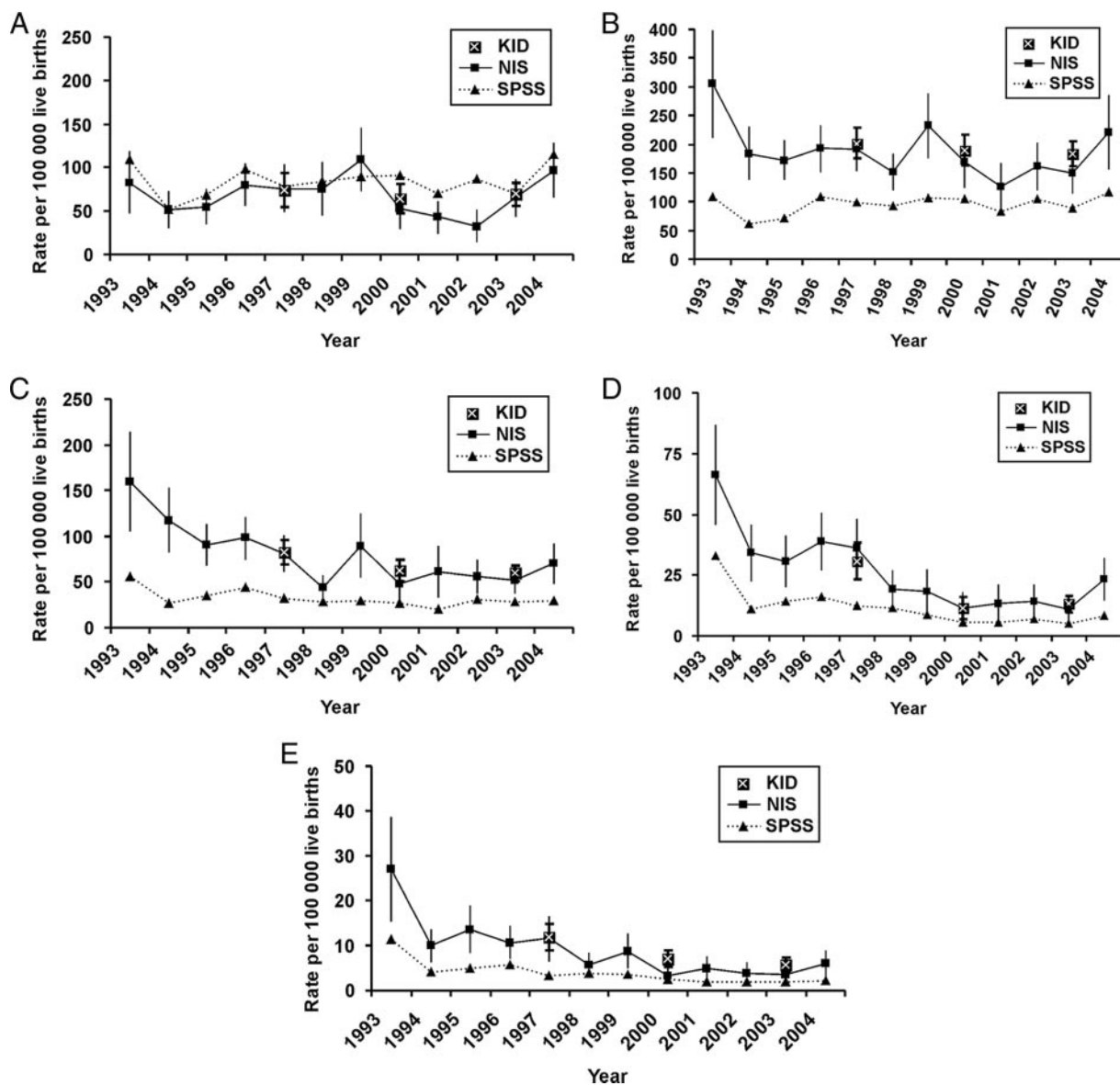


FIGURE 2 Pertussis hospitalization rates according to age group in the KID, NIS, and SPSS (1993–2004). A, 0 months; B, 1 to 2 months; C, 3 to 4 months; D, 5 to 6 months; E, 7 to 11 months. Rate calculations for these figures were based on nonimputed data only. CIs (95%) are presented for KID and NIS estimates. Ranges on the y-axis differ according to age group.

infants 1 to 2 months of age occurred in 1993 (305 hospitalizations per 100 000 live births), 1999 (259 hospitalizations per 100 000 live births), and 2004 (292 hospitalizations per 100 000 live births). In each age group, the rates derived from the KID were approximately the same or slightly higher than those derived from the NIS (median KID/NIS ratio: 1997: 1.1:1; 2000: 1.2:1; 2003: 1.1:1) (Table 2 and Fig 2). Incidence rates for female infants were slightly higher than those for male infants (female/male ratio for <1 year of age in the KID: 2000: 1.13:1; 2003: 1.06:1).

When imputed data were included in the rate estimates, the pertussis hospitalization rates in the KID and SPSS were similar for infants 0 months of age but KID rates were ~2 to 2.5 times higher than SPSS rates for other age groups (median KID/SPSS ratio: 1997: 2.6:1;

2000: 2.3:1; 2003: 2.0:1) (Table 2). For infants 1 to 2 months of age, 2003 hospitalization rates were 239 hospitalizations per 100 000 live births (KID), 209 hospitalizations per 100 000 live births (NIS), and 114 hospitalizations per 100 000 live births (SPSS).

In the single-month age groups, 1-month-old infants had the highest incidence of pertussis hospitalization in the KID (Fig 3). In the KID for 2000 and 2003, 61% of pertussis hospitalizations involved infants 1 to 2 months of age and 86% of hospitalizations involved infants 0 to 3 months of age.

Complications in KID in 2000 and 2003

Pertussis was listed as the primary diagnosis in 80% and 78% of total cases in 2000 and 2003, respectively. For infants with a non-pertussis code listed first, the top

TABLE 2 Number of Pertussis Hospitalizations and Incidence Rate of Pertussis Hospitalization Among Infants According to Age Group in 1997, 2000, and 2003, From SPSS and KID

	0 mo		1–2 mo		3–4 mo		5–6 mo		7–11 mo		Total <1 y	
	SPSS	KID	SPSS	KID	SPSS	KID	SPSS	KID	SPSS	KID	SPSS	KID
1997												
No.	257	274	659	1483	211	607	82	227	54	167	1263	2758 (95% CI: 2462–3054) ^a
Rate, hospitalizations per 100 000 live births	80	85	102	229	37	94	13	35	3	10	33	71 (95% CI: 63–79)
2000												
No.	326	279	784	1652	204	544	64	99	65	111	1443	2685 (95% CI: 2387–2983) ^a
Rate, hospitalizations per 100 000 live births	97	82	116	244	30	80	6	15	3	6	34	66 (95% CI: 59–74)
2003												
No.	306	307	780	1627	265	528	45	116	44	93	1440	2670 (95% CI: 2397–2943) ^a
Rate, hospitalizations per 100 000 live births	90	90	114	239	39	77	7	17	3	6	35	65 (95% CI: 59–72)

Age at hospital admission is calculated for the KID data, whereas age at cough onset is calculated for the SPSS data. The SPSS data include cases with hospitalization status imputed. The KID data are weighted numbers, and include cases with age in month imputed for all age groups except for the group Total < 1 year.

^a Number of hospitalizations, unweighted: 1188 in 1997, 1425 in 2000, and 1567 in 2003.

codes listed first were those for acute bronchiolitis due to another organism (21% in 2000 and 28% in 2003) and respiratory syncytial virus (RSV) infection/pneumonia/bronchiolitis (20% and 28%, respectively).

Of the complications examined, apnea/respiratory distress was the most frequently diagnosed complication in both years (Table 3), coded on average for 19% of infants. Pneumonia (all types, and “pneumonia, in whooping cough”), the second most common complication, was most frequently coded among infants 0 months of age (14%–18%). Gastroesophageal reflux was coded for 12% of infants and RSV infection for 5%. In 2000, the infants with encephalitis for whom age in months was provided were 3 months of age; in 2003, the infants were 0 to 2 months of age.

Mechanical ventilation was coded for 11% and 15% of infants 0 months of age in 2000 and 2003, respectively, and the proportion decreased with increasing age. Of the infants who underwent mechanical ventilation for whom age in months was provided, 95% were ≤ 3 months of age; the oldest in 2000 was 4 months of age, and the oldest in 2003 was 5 months of age. Extracorporeal membrane oxygenation was coded for 14 infants in 2000 (oldest: 3 months of age) and 7 infants in 2003

(oldest: 2 months). A fatal outcome was recorded for 18 infants in 2000 and 14 infants in 2003, all ≤ 3 months of age.

A small proportion of infants <1 year of age had diagnosis codes that indicated possible significant underlying cardiac or pulmonary disease ($\leq 4\%$ per category) (Table 3). The lengths of hospitalization stay were similar in the 2 years, and the youngest infants had the longest stays (Table 3).

DISCUSSION

We examined pertussis hospitalizations among infants during the period 1993 to 2004 by using 2 national inpatient discharge databases and the national surveillance system. The rates derived from the NIS suggest that the incidence of pertussis hospitalizations in infants ≤ 2 months of age was generally stable during this period. In contrast, rates from the SPSS were approximately one half the rates from the NIS or KID, and the imputed SPSS data suggested an increase in incidence for infants ≤ 2 months of age. The increase seems to rely heavily on the results from 2004, the year with the greatest number of pertussis cases reported (25 827 in all age groups combined) since 1959.¹⁸ Although an infant must be diag-

FIGURE 3 Average annual incidence of pertussis hospitalizations and number (percent) of hospitalizations according to age group in the KID (2000 and 2003).

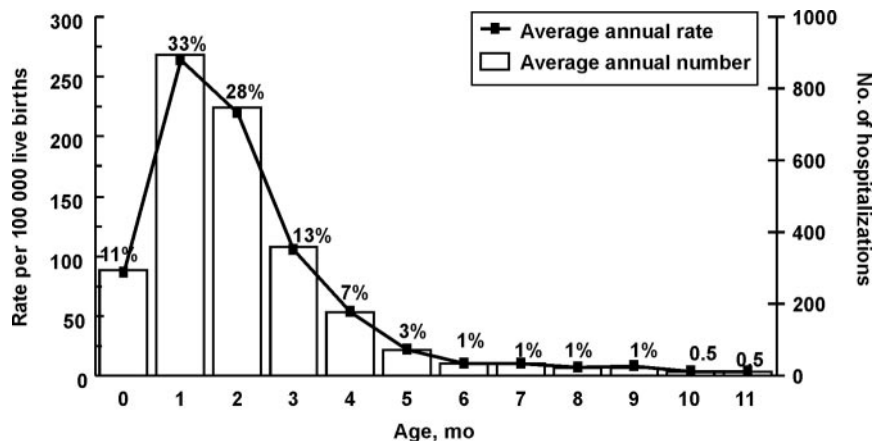


TABLE 3 Diagnoses and Procedures for Infants Hospitalized With Pertussis, Proportion of All Pertussis Hospitalizations According to Age Group, and Length of Hospitalization, From KID

	Weighted No. of Infants <1 y With Specific Complication ^a	Proportion of Hospitalized Infants in Each Age Group With Specific Complication, % ^{a,b}						Proportion of Total Infants With Specific Complication in Each Age Group, %	
		<1 y	0 mo	1–2 mo	3–4 mo	5–6 mo	7–11 mo	0–1 mo	0–3 mo
Pertussis hospitalizations, overall	2678							44	86
Diagnoses									
Apnea or respiratory distress ^c	496	19	18	20	17	15	15	51	89
Pneumonia, all types	346	13	18	13	11	20	14	46	86
Pneumonia, "in whooping cough"	252	9	14	10	7	11	12	45	87
Gastroesophageal reflux	315	12	12	10	12	10	9	44	84
RSV	139	5	5	5	5	6	7	42	84
Seizures, nonfebrile	41	2	3	1	1	1	1	50	84
Pneumothorax	8 ^d	0.3	0.4	0.2	0.7	0	0	41	100
Encephalopathy/encephalitis	5 ^d	0.2	0.4	0.1	0.2	0	0	50	50
Procedures									
Mechanical ventilation	142	5	13	5	2	2	0	70	95
ECMO	10 ^d	0.4	1.3	0.3	0.3	0	0	58	100
Death	16 ^d	0.6	1.2	0.6	0.5	0	0	56	100
Additional conditions^e									
Congenital heart disease ^f	89	3							
Pulmonary disease, any	98	4							
Asthma	81	3							
Perinatal chronic lung disease	11 ^d	0.4							

Average annual results for 2000 and 2003 are presented. Median length of stay values were as follows: <1 year of age, 4 days; 0 months, 6 days (range: 0–131 days); 1 to 2 months, 4 days (range: 0–75 days); 3 to 4 months, 3 days (range: 0–59 days); 5 to 6 months, 3 days (range: 0–48 days); 7 to 11 months, 2 days (range: 0–15 days). ECMO indicates extracorporeal membrane oxygenation.

^a Infants could be counted in >1 category.

^b Age distribution of complications based on weighted proportions of those with data on age in months available.

^c Includes apnea, primary apnea of newborn, respiratory distress, arrest, insufficiency, or asphyxia.

^d Relative SE (SE/estimate) was ≥ 0.30 for each year; therefore, the annual average estimate is unreliable.

^e General categories with weighted results of ≥ 27 cases each year (1% of pertussis cases).

^f Includes 3 infants (in 2000) and 4 infants (in 2003) with cardiac surgery during hospitalization.

nosed as having pertussis to be counted in any of the systems, cases in the SPSS must also be reported by a health care professional to the health department. Improved reporting over the study period likely accounted for the increase in hospitalization rates for the youngest infants observed in the SPSS. However, the proportion of infants for whom hospitalization status was missing in the SPSS increased over time, which indicated that reporting did not improve in all aspects.

With the exception of infants 0 months of age, incidence rates of pertussis hospitalizations from the NIS and KID were ~2 times greater than those from the SPSS. Sutter and Cochi¹⁹ performed a capture-recapture analysis for the period from 1985 to 1988 and found that only 34% of hospitalizations for infants diagnosed as having pertussis had been reported to the SPSS. Because it was not possible to link discharge records in the NIS and KID databases with individual records from another source, we could not determine whether NIS or KID rates still underestimated the true rates of hospitalization for diagnosed pertussis. Underestimation also could occur if pertussis was never diagnosed because of limitations in pertussis laboratory diagnostic testing^{20,21} or atypical clinical presentation.

The highest incidence of pertussis hospitalization occurred among infants 1 month of age, younger than the

age at which the first dose of diphtheria/tetanus/acellular pertussis (DTaP) vaccine is generally recommended (2 months of age). The incidence for infants 0 months of age was lower than for infants 1 month of age. One explanation for this lower rate is that, because the incubation period is usually 7 to 10 days (range: 5–21 days), infants who are hospitalized at 0 months of age would have to be exposed during the first 2 weeks of life and develop significant symptoms quickly after a short incubation period. Those with a longer incubation period and/or more-gradual onset of symptoms would be 1 month of age at hospitalization. Less exposure to pertussis among infants 0 months of age may also explain lower rates in infants 0 months of age. Finally, although contemporary US data demonstrate low levels of maternal pertussis antibodies in newborns, it is theoretically possible that there is some degree of protection from transplacentally transferred antibody that diminishes by 1 month of age.^{22–25}

From the peak incidence rate in the KID among infants 1 month of age, the rate decreased precipitously to 3 months of age and continued to decrease to 6 months of age. This pattern is most likely explained by the corresponding increase in pertussis vaccine coverage, as assessed by the National Immunization Survey (Fig 4).^{3,26,27} The 60% lower incidence rate among infants 3

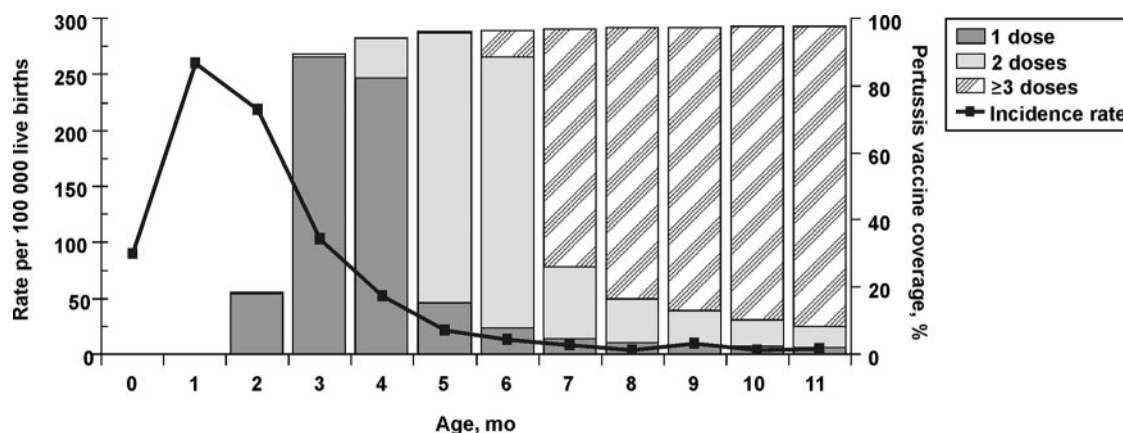


FIGURE 4

Incidence of pertussis hospitalization and infant pertussis vaccine coverage in the United States according to age group in the 2003 KID and 2005 National Immunization Survey. Shown are the number of doses of DTaP, diphtheria/tetanus/pertussis, or diphtheria/tetanus vaccine received by the beginning of the age month; data are for children born between February 2002 and July 2004. The incidence rate among infants 2 months of age (218 hospitalizations per 100 000 live births) was 16% lower than that among infants 1 month of age (260 hospitalizations per 100 000 live births); by the age of 2 months, 18.3% of infants had received 1 DTaP vaccine dose and an additional 0.1% had received 2 doses. The incidence rate among infants 3 months of age (103 hospitalizations per 100 000 live births) was 60% lower than that among infants 1 month of age; by the age of 3 months, 89.3% of infants had received 1 DTaP vaccine dose and an additional 0.5% had received 2 doses.

months of age, compared with infants 1 month of age, suggests that even 1 dose of DTaP vaccine provides protection against hospitalization with pertussis. Among infants 2 to 3 months of age with pertussis, Tanaka et al² found lower odds ratio of hospitalization (0.69; 95% CI: 0.61–0.79) for infants who had received 1 dose of DTaP vaccine, compared with unimmunized infants.

The lower hospitalization rate among infants 3 months of age, compared with infants 1 month of age, might also result from factors other than immunization. For example, physicians might be more likely to hospitalize a 1-month-old infant than a 3-month-old infant with suspected pertussis, regardless of immunization status. Even if the younger group could be immunized, there might be physiologic (eg, cardiorespiratory) differences between these ages that would still necessitate more pertussis hospitalizations among the youngest infants.²⁸ However, infants ≤ 2 months of age have the highest incidence of pertussis hospitalization, and routinely giving the first dose of DTaP vaccine as soon as infants reach 2 months of age (or perhaps even 6 weeks of age, the lowest end of the eligibility range) is warranted.

The youngest infants hospitalized with pertussis had the greatest risk of requiring mechanical ventilation or extracorporeal membrane oxygenation, having encephalopathy, or dying. Our proportions of hospitalized infants < 1 year of age who had apnea/respiratory distress, pneumonia, seizures, or encephalopathy or who died were similar to those reported by O'Brien and Caro,²⁹ who used discharge databases from 4 states covering 1996 to 1999. In their study, 14% of infants received care in a NICU or PICU, a variable not available in our databases. Data from national inpatient active surveillance networks in Canada³⁰ and Australia³¹ reported rates of pneumonia, seizures, encephalopathy, and death among infants similar to those we obtained from the KID.

Other diagnoses were also made in infants with per-

tussis. RSV coinfection (5% in our study) was not unexpected, given the high incidence of RSV in infants. Crowcroft et al³² found RSV coinfection in 9 (36%) of 25 infants with pertussis who required ICU care in the United Kingdom during the non-RSV season. In our study, approximately 10% of infants were coded as having gastroesophageal reflux. It is not known whether this was considered a separate condition or a diagnosis describing the feeding problems (eg, posttussive vomiting) caused by pertussis. Few infants had additional codes for underlying cardiac or respiratory conditions. Information on gestational age was not available in the KID.

Estimates of complications from the KID based on small numbers should be interpreted with caution because they are unreliable. In addition, deaths that occurred at home or in the emergency department would not be captured in the KID. The numbers of infant pertussis deaths estimated from the KID (18 deaths in 2000 and 14 deaths in 2003), however, are remarkably close to the numbers of infant pertussis deaths reported to the National Notifiable Disease Surveillance System/SPSS (17 deaths in 2000 and 15 deaths in 2003) (Centers for Disease Control and Prevention, unpublished data, 2006).

Our analyses had other limitations. Age was calculated differently in the SPSS (age at cough onset) and the databases (age at hospital admission), which might have affected comparisons. However, because infants with pertussis who are hospitalized are most likely admitted within several days after illness onset, the difference in age definition was not a likely explanation for the higher rates in the NIS or KID.

An important limitation of the rate estimates concerns missing data for hospitalization status in the SPSS and for age in months in the NIS and KID. The proportion of cases with missing hospitalization status in the SPSS increased over time; for several states in recent

years, none of the reported pertussis cases had information on hospitalization status. Although we think that a certain proportion of these infants were truly hospitalized, the accuracy of our imputation procedure is not known. We imputed data on age in months for infants whose ages were coded only as 0 years in the NIS and KID. However, we have no reason to think that the distribution of age in months at hospital admission among the 4 or 5 states with age coded as 0 years was different from that for the states with available data on age in months. Finally, the accuracy of International Classification of Diseases, Ninth Revision, coding for pertussis in the NIS or KID is not known.

With a goal of reducing infant exposure to *B pertussis*, the Advisory Committee on Immunization Practices recently recommended that, as a priority group, persons in close contact with infants should be immunized with tetanus/diphtheria/acellular pertussis vaccine (Tdap).^{20,33} This vaccine is also recommended for all adolescents and adults ≤ 65 years of age. Implementing these recommendations may lead to decreased circulation of *B pertussis* in the general population. In addition to strategies to reduce infant exposure, other strategies that should be fully evaluated are passively protecting infants by vaccinating pregnant women and actively immunizing infants early (even before 2 months of age).³⁴

For any illness, changes can occur over time in hospitalization practices, testing practices, and methods used to make the diagnosis. The degree to which such changes affect trends observed in hospitalization rates from any data source can be difficult to quantify. Surveillance systems, like the SPSS, that rely on reported data are also subject to changes in reporting, another factor that is difficult to quantify and to control for in analyses. Assuming that the higher rates in the NIS and KID better reflect the true incidence of pertussis hospitalizations, our analysis suggests that, at least beginning with 1993, a large margin exists in which improved reporting to the SPSS could account for any observed increase in infant pertussis hospitalizations.

Nationally representative discharge databases are useful for monitoring infant pertussis hospitalizations. The impact on infant pertussis of the use of the new Tdap vaccines for adolescents and adults should be monitored through such discharge databases.

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APPENDIX International Classification of Diseases, Ninth Revision, Clinical Modification Codes Used for Analysis of KID 2000 and 2003 Data Among Infants With Pertussis Codes

	Code
Diagnosis codes	
Pneumonia, "in whooping cough"	484.3
Pneumonia, other types	480.2, 480.8, 480.9, 481, 482.0, 482.1, 482.2, 482.82, 482.83, 482.9, 483.0, 483.1, 484.3, 485, 486, 487.0, 770.0
Pneumothorax	512.0, 512.8
Apnea	786.03, 770.81
Seizures	779.0, 780.39, 345.3
Encephalopathy/encephalitis	323.6, 348.30
Acute respiratory failure, other pulmonary insufficiency, respiratory distress, asphyxia	518.81, 518.82, 786.09, 799.0, 799.1
Gastroesophageal reflux	530.81
RSV	466.11, 796, 480.1
Procedure codes	
ECMO	39.65
Mechanical ventilation	96.70, 96.71, 96.72
Codes used for underlying conditions	
Diagnosis codes	
Pulmonary	
Perinatal chronic lung disease	770.7
Asthma	493.00, 493.02, 493.90, 493.91, 493.92
Other	277.00, 277.02, 277.03, 518.84, 553.3, 748.5
Congenital heart disease	397.0, 424.0, 424.1, 424.3, 745.2, 745.4, 745.5, 746.02, 746.3, 746.5, 746.89, 747.0, 747.10, 747.3, 747.21, 747.41
Procedure codes	
Cardiac surgery	35.62, 35.71, 35.81, 35.92, 38.34

At least 1 infant had each listed code. ECMO indicates extracorporeal membrane oxygenation.

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