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PERTUSSIS, A RESPIRATORY ILLNESS caused by Bordetella pertussis, is characterized by a paroxysmal cough that can last for several weeks. In the prevaccine era, pertussis was a major cause of morbidity and mortality among infants and children in the United States, with a mean of more than 160 000 cases and more than 5000 deaths reported annually in the 1920s and 1930s. After the introduction of whole-cell pertussis vaccine combined with diphtheria and tetanus toxoids in the 1940s, reported cases of pertussis decreased more than 99%, reaching a nadir of 1010 cases in 1976. After the introduction of whole-cell pertussis vaccine combined with diphtheria and tetanus toxoids in the 1940s, reported cases of pertussis decreased more than 99%, reaching a nadir of 1010 cases in 1976.5

After 1976, the number of reported cases of pertussis progressively increased, while maintaining the 3- to 4-year cyclicity characteristic of the prevaccine era. The incidence of reported cases of pertussis increased among all age groups, but especially among adolescents and adults. The relative contributions to the increase in reports from heightened awareness of pertussis among adolescents and adults, improved surveillance, and the real increase in disease remain unclear.

Among all age groups, infants (aged <12 months) have had the highest incidence of pertussis in the vaccine era, and infants account for the overwhelming majority of hospitalizations, serious complications, and deaths from pertussis. Because pertussis is a well-known disease among infants, case ascertainment and disease reporting may be more consistent among infants than among older age groups. To describe the trends and characteristics of reported infant pertussis cases in the United States, we analyzed the national database of cases among infants for the period of 1980-1999 and determined the characteristics of cases in the 1990s.

METHODS

Case Definitions
Pertussis has been a notifiable disease in the United States since the 1920s.

Context  Reported cases of pertussis among adolescents and adults have increased since the 1980s, despite increasingly high rates of vaccination among infants and children. However, severe pertussis morbidity and mortality occur primarily among infants.

Objective  To describe the trends and characteristics of reported cases of pertussis among infants younger than 12 months in the United States from 1980 to 1999.


Main Outcome Measures  Incidence and demographic and clinical characteristics of cases.

Results  The incidence of reported cases of pertussis among infants increased 49% in the 1990s compared with the incidence in the 1980s (19798 vs 12550 cases reported; 51.1 cases vs 34.2 cases per 100 000 infant population, respectively). Increases in the incidence of cases and the number of deaths among infants during the 1990s primarily were among those aged 4 months or younger, contrasting with a stable incidence of cases among infants aged 5 months or older. The proportion of cases confirmed by bacterial culture was higher in the 1990s than in the 1980s (50% and 33%, respectively); the proportion of hospitalized cases was unchanged (67% vs 68%, respectively). Receipt of fewer doses of vaccine was associated with hospitalization, when cases were stratified by age in months.

Conclusions  The incidence of reported cases of pertussis among infants increased in the 1990s compared with the 1980s. The increased rate of bacteriologic confirmation, and the unchanged severity of illness suggest that an increase in infant pertussis has occurred apart from any change in reporting. Strategies are needed to prevent the morbidity and mortality from pertussis among infants too young to be fully vaccinated, according to the current recommended schedules of vaccination in the United States.

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investigate these reports and determine if they should be reported as cases of pertussis. Data about these cases are reported by state health departments to the Centers for Disease Control and Prevention (CDC).

In 1990, case definitions for pertussis were recommended by CDC and the Council of State and Territorial Epidemiologists (CSTE) for the national surveillance of pertussis; minor revisions were made in 1996. The definition of clinical case for an endemic or sporadic case of pertussis is a cough illness lasting 2 weeks or longer with at least 1 of the following: paroxysms of coughing, inspiratory “whoop,” or post-tussive vomiting, without other apparent cause. In outbreak settings, a case may be defined by a cough illness lasting 2 weeks or longer without other criteria. Isolation of B pertussis was required for laboratory confirmation in the early 1990s; the test has relatively low yield in routine use but is the standard for the diagnosis of pertussis. Some states began reporting the result of polymerase chain reaction (PCR) for B pertussis DNA in 1995, and a positive result was accepted by CDC/CSTE as an additional confirmatory test in 1996. The CDC/CSTE does not recommend the use of direct fluorescent antibody (DFA) test for laboratory confirmation, because some studies have documented that DFA testing of nasopharyngeal secretions has low sensitivity and variable specificity, but the test is still commonly used in some states.

Although all cases reported through the national surveillance system were considered to be pertussis by a clinician or public health official, some were lacking data needed to classify them according to the CDC/CSTE criteria. For this report, cases of pertussis were reclassified as confirmed or probable if they met CDC/CSTE criteria for endemic/sporadic cases. A confirmed case was defined as a case with an acute cough illness of any duration that was culture-positive, or a case that met the clinical case definition and was confirmed by polymerase chain reaction, or a case that met the clinical case definition and was epidemiologically linked to a laboratory-confirmed case. A probable case of pertussis was one that met the clinical case definition, was not laboratory-confirmed, and was not epidemiologically linked to a laboratory-confirmed case. Cases with unknown status were those cases that did not have sufficient information reported to classify them as confirmed or probable.

National Surveillance System
In the 1980s and 1990s, CDC maintained a national surveillance system for pertussis in the United States, the National Notifiable Disease Surveillance System (NNDSS). The objective of NNDSS was timely passive reporting from state and local surveillance personnel of pertussis cases with basic information such as year of disease, age of cases in years, and disease outcome. Data from NNDSS are published weekly by CDC in the Morbidity and Mortality Weekly Report (MMWR). The Supplementary Pertussis Surveillance System (SPSS) was introduced in 1979 to obtain more detailed information about pertussis cases reported to NNDSS, such as dates of birth and disease onset, vaccination status, laboratory results, symptoms, and complications. The number of infant cases for which SPSS information was available was 86% of the number of infant cases reported to NNDSS in the 1980s and 93% of cases reported to NNDSS in the 1990s. By 1984, the number of infant cases with supplementary information reported through SPSS reached a figure comparable with reports through NNDSS. Since 1996, cases from the 2 systems have been reconciled into a single database.

Pertussis Vaccination Status
We used the routine schedule for pertussis vaccination recommended by the Advisory Committee on Immunization Practices (ACIP) to determine whether infants with pertussis were age-appropriately vaccinated at the onset of pertussis. The timing of recommended doses of pertussis vaccine for infants (2, 4, and 6 months of age) has not changed since 1977; the recommendations allow the first dose of pertussis-containing vaccine to be given as early as 6 weeks of age. Subsequent doses are given at a minimum interval of 4 weeks. In defining the minimum number of doses an infant should have received to be age-appropriately vaccinated at a given age in months, we allowed a grace period of 1 month from the recommended schedule.

Infants received either diphtheria and tetanus toxoids and acellular pertussis vaccines (DTaP) or diphtheria and tetanus toxoids and whole-cell pertussis vaccines (DTP) for the first 3 doses. Until mid-1996, DTWP vaccines were the only licensed preparations for the first 3 doses. In the United States, DTaP vaccines were recommended for the fourth and fifth dose by the ACIP in 1992. In July 1996, DTaP vaccines were recommended for infants starting at 2 months of age and subsequently replaced DTWP vaccines. Data on the type of vaccine received at the individual case level usually were not available from surveillance reports. For this reason, DTWP and DTaP vaccines are collectively denoted as diphtheria, tetanus, and pertussis vaccine (DTP) in this article.

Analytical and Statistical Methods
To ensure consistency with previously published analyses, we included all nationally reported cases of pertussis among infants younger than 12 months at the time of disease; we excluded cases reported from Puerto Rico and other overseas territories. Data from NNDSS were used to determine the total number of infant cases and deaths by year. For all other analyses, we used detailed data from the SPSS database. The SPSS data since 1984 were used for calculations of incidences. The denominator for calculated incidence rates among specific age or ethnic groups was restricted to the US population estimate that represented the group of interest. Reporting of race and ethnicity began in 1995, but was incomplete; we restricted the analysis of race and ethnicity to cases reported in 1997-1999.
when the reporting of the information improved. Population demographic data were obtained from intercensal estimates from the National Census Bureau.14 Statistical analyses were performed using Microsoft Excel 2002 (Microsoft, Redmond, Wash) and Epi Info (version 6.04, CDC, Atlanta, Ga).

RESULTS

Incidence of Pertussis

During the 1990s, a total of 19798 cases of pertussis among infants younger than 12 months were reported through NNDSS and 12550 cases were reported in the 1980s. Cases among infants accounted for 35% of all pertussis cases reported in the 1990s. The annual number of reported cases of pertussis among infants increased progressively during the last 2 decades with peaks every 3 to 4 years (FIGURE 1). In the 1990s compared with the 1980s, the mean annual number of cases among infants reported through NNDSS increased by 58% (1980 cases vs 1255 cases, respectively), and the mean annual incidence increased by 49% (51.1 vs 34.2 cases per 100 000 infant population, respectively).

During the 1990s, 18500 infant cases were reported through SPSS; 50.6% were male. Cases among infants 4 months or younger accounted for 77% (14311 cases) of all infant cases reported through SPSS and 27% of pertussis cases of all ages during the 1990s. The mean annual incidence rate among infants 4 months or younger increased from 63.4 cases per 100 000 population in the 1980s to 88.7 cases per 100 000 in the 1990s; the mean annual incidence rate among Diphtheria and tetanus toxoids and acellular pertussis vaccines were introduced for infant use in 1996. Data are from the Supplementary Pertussis Surveillance System.12

The 1980s include data from 1984 to 1989 and the 1990s include data from 1990 to 1999. Data are from the Supplementary Pertussis Surveillance System.12
Infants aged 2 months or younger increased by 49%, from 72.1 cases in the 1980s to 107.3 cases per 100000 in the 1990s (Figure 2, Figure 3). The mean annual incidence among infants aged 5 to 11 months changed little (20.2 cases per 100000 in the 1980s and 18.6 cases per 100000 in the 1990s) (Figures 2 and 3).

Results of Laboratory Examinations
Among 18500 infant cases reported through SPSS in the 1990s, 10161 cases (55%) were confirmed; 9231 (50%) cases were culture-confirmed by isolation of B pertussis. In contrast, among 10859 infant cases reported through SPSS in the 1980s, 3604 (33%) were culture-confirmed. In the 1990s, 706 (4%) cases were confirmed by a positive polymerase chain reaction assay, and 224 (1%) were confirmed by epidemiological linkage to a laboratory-confirmed case. Results of DFA testing of nasopharyngeal secretions for B pertussis were reported for 6794 (67%) of the 10161 confirmed cases in the 1990s; 4170 (61%) DFA tests were positive. Among 5688 cases (31%) classified as probable cases, 3123 (55%) had a positive DFA test. An additional 2651 cases (14%) were unable to be categorized; 1527 (58%) of these cases had a positive DFA test. This contrasts with 42% of cases that were unable to be characterized in the 1980s.

The mean annual incidence of culture-confirmed cases among infants increased in the 1990s compared with the 1980s (24.0 and 13.2 per 100000 infant population, respectively). In the 1990s, the proportion of cases that were culture-tested increased (67% in the 1990s vs 50% in the 1980s; P<.001), and the proportion of cases with a positive result among those culture-tested also increased (75% in the 1990s vs 66% in the 1980s; P<.001).

Vaccination Status
In the 1990s, 7387 cases (91%) of the 8116 reported cases among infants aged 3 to 11 months had information about vaccination with DTP; in the 1980s, 5540 (95%) of cases in this age group had the information. The proportion of cases age-appropriately vaccinated was higher in the 1990s than in the 1980s (Table 1).

Clinical Characteristics of Cases in the 1990s
Classic symptoms of pertussis, cough and paroxysm, were common among infant cases regardless of age in months (Table 2). Among hospitalized cases, the mean length of hospitalization was 7.0 days in the 1990s. The proportions of cases with whoop and with vomiting increased with increasing age; the proportions of cases with apnea and cases hospitalized decreased with increasing age. The proportion of cases hospitalized was 67% in the 1990s and 68% in the 1980s. We examined the relationship between age in months and clinical symptoms or hospitalization. For this analysis we stratified by age in months. Among cases aged 6 to 11 months with known vaccination status, 0 dose compared with 3 doses was a risk factor for whomp (OR, 1.53; 95% confidence interval [CI], 1.24-1.87), apnea (OR, 1.25; 95% CI, 1.02-1.53), and pneumonia (OR, 1.54; 95% CI, 1.12-2.12). Irrespective of age, infants with pertussis who received fewer DTP vaccinations were significantly more likely to be hospitalized (Table 3).

During the 1990s, 93 (90%) of 103 reported pertussis-related fatalities were among infants, compared with 61 (79%) of 77 reported pertussis-related fatalities during the 1980s; the case-fatality rate among infants was 0.5% in

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Table 2. Age, Manifestation, and Complications of Reported Infant Pertussis Cases, United States, 1990-1999*

<table>
<thead>
<tr>
<th>Infant Age, mo</th>
<th>0-1</th>
<th>2-3</th>
<th>4-5</th>
<th>6-7</th>
<th>8-9</th>
<th>10-11</th>
<th>Total Infant Cases</th>
<th>Cases With Missing Information, %†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of cases</td>
<td>6989</td>
<td>5557</td>
<td>2848</td>
<td>1424</td>
<td>919</td>
<td>763</td>
<td>18500</td>
<td>0</td>
</tr>
<tr>
<td>Cases with manifestation/complication, %‡</td>
<td>99.7</td>
<td>99.8</td>
<td>99.8</td>
<td>99.6</td>
<td>99.9</td>
<td>99.6</td>
<td>99.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Cough (any duration)</td>
<td>85</td>
<td>86</td>
<td>85</td>
<td>85</td>
<td>86</td>
<td>85</td>
<td>85</td>
<td>10.7</td>
</tr>
<tr>
<td>Cough (≥14 d)</td>
<td>90</td>
<td>91</td>
<td>91</td>
<td>90</td>
<td>90</td>
<td>89</td>
<td>91</td>
<td>6.1</td>
</tr>
<tr>
<td>Paroxysm</td>
<td>58</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>62</td>
<td>60</td>
<td>9.9</td>
</tr>
<tr>
<td>Whoop</td>
<td>66</td>
<td>68</td>
<td>69</td>
<td>71</td>
<td>71</td>
<td>73</td>
<td>68</td>
<td>6.9</td>
</tr>
<tr>
<td>Apnea</td>
<td>64</td>
<td>55</td>
<td>48</td>
<td>45</td>
<td>43</td>
<td>44</td>
<td>56</td>
<td>7.7</td>
</tr>
<tr>
<td>Pneumonia§</td>
<td>23</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>24</td>
<td>22</td>
<td>22</td>
<td>36.7</td>
</tr>
<tr>
<td>Seizure</td>
<td>2.6</td>
<td>1.3</td>
<td>1.7</td>
<td>1.5</td>
<td>1.9</td>
<td>2.0</td>
<td>1.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Encephalopathy</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>2.9</td>
</tr>
<tr>
<td>Hospitalization</td>
<td>82</td>
<td>68</td>
<td>53</td>
<td>48</td>
<td>41</td>
<td>36</td>
<td>67</td>
<td>3.1</td>
</tr>
<tr>
<td>Death</td>
<td>1.0</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*Data are from Supplementary Pertussis Surveillance System.12 Infants could have received diphtheria and tetanus toxoids and acellular pertussis vaccines (DTaP) or diphtheria and tetanus toxoids and whole-cell pertussis vaccines (DTwP) during the period of analysis.†Proportion of cases unknown for presence of each manifestation/complication in the total reported infant cases.‡Proportion among cases with information on each manifestation/complication in each age group.§Confirmed by radiographs.

Table 3. Dose of DTP Vaccination and Odds of Hospitalization Among Reported Infant Pertussis Cases, United States, 1990-1999, Age-Stratified Analysis*

<table>
<thead>
<tr>
<th>Age Group, mo†</th>
<th>No. of Doses Compared</th>
<th>Odds Ratio (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3</td>
<td>0 vs 1</td>
<td>1.44 (1.26-1.64)</td>
</tr>
<tr>
<td>4-5</td>
<td>0 vs 1</td>
<td>1.02 (0.82-1.27)</td>
</tr>
<tr>
<td></td>
<td>0 vs 2</td>
<td>1.84 (1.48-2.26)</td>
</tr>
<tr>
<td></td>
<td>1 vs 2</td>
<td>1.79 (1.50-2.15)</td>
</tr>
<tr>
<td>6-11</td>
<td>0 vs 1</td>
<td>0.91 (0.73-1.15)</td>
</tr>
<tr>
<td></td>
<td>0 vs 2</td>
<td>1.08 (0.87-1.35)</td>
</tr>
<tr>
<td></td>
<td>0 vs 3</td>
<td>2.17 (1.78-2.64)</td>
</tr>
<tr>
<td></td>
<td>1 vs 2</td>
<td>1.18 (0.93-1.51)</td>
</tr>
<tr>
<td></td>
<td>1 vs 3</td>
<td>2.37 (1.90-2.96)</td>
</tr>
<tr>
<td></td>
<td>2 vs 3</td>
<td>2.00 (1.62-2.48)‡</td>
</tr>
</tbody>
</table>

†Data are from Supplementary Pertussis Surveillance System.12 Infants could have received diphtheria and tetanus toxoids and acellular pertussis vaccines (DTaP) or diphtheria and tetanus toxoids and whole-cell pertussis vaccines (DTwP) during the period of analysis.‡Odds ratio (95% confidence interval) for age subgroups: 6-7 months, 1.84 (1.35-2.49); 8-9 months, 1.65 (1.09-2.51); and 10-11 months, 2.60 (1.36-4.98). Odds of hospitalization for infants aged 5 to 6 months (0 vs 2 doses): 1.71 (1.31-2.22).

Both decades. Among reported pertussis deaths of all ages, the proportion of infants younger than 4 months increased from 64% in the 1980s to 82% in the 1990s. In the 1990s, of 25 infant death cases aged 2 months or older (and therefore who had been eligible for routine vaccination), 15 had received no pertussis vaccine.

Race and Hispanic Ethnicity
Data on race were available for 4224 (68%) of the 6172 infant cases reported during 1997-1999; 78% were white and 17% were African American. Of the 4304 cases with data on ethnicity, 29% were identified as Hispanic. Although national reporting of ethnicity remains incomplete, 6 states (Arizona, California, Connecticut, Florida, New Mexico, and Texas) had more than 90% complete reporting on ethnicity for infant pertussis cases and more than 5% Hispanics among their infant populations in 1997-1999. In these states, the mean annual incidence of pertussis among Hispanic infants was 68 per 100000 infant population, 74% higher than among non-Hispanic infants (39 per 100000).

Geographic Distribution
In the 1990s, the mean annual incidence of pertussis among infants by state ranged from 10 to 133 cases per 100000 in Mississippi and Idaho, respectively (SPSS data). Substantial year-to-year variation in the incidence was observed by state, but some states, such as Idaho, New Hampshire, Hawaii, Minnesota, Colorado, and Washington, consistently reported mean annual incidences higher than 100 cases per 100000 infant population. Other states, such as Mississippi, Alabama, Florida, New Jersey, Louisiana, and South Carolina, consistently reported low incidences throughout the 1990s (<50% of the national average of 51 cases per 100000 infant population). Most states in the southern Atlantic, eastern south-central, and western south-central regions reported lower than the national average annual incidences; most states in New England reported higher than the national average annual incidences (data not shown).

Seasonality
During the 1990s, 46% of reported infant pertussis cases had an onset of cough
between June and September (Figure 4). For 27% of the cases, the onset was in July and August; the summer peak was less pronounced for infant cases aged 4 months or younger compared with infant cases older than 4 months. The peak pattern among infant cases aged 4 months or younger was similar to cases aged 5 to 9 years and cases 20 years or older, and the pattern among cases aged 5 to 11 months was similar to cases aged 1 to 4 years. Nationally, pertussis cases among adolescents peaked in the fall months of the year, although there was variation by state.

**COMMENT**

National surveillance data show a progressive increase in reports of pertussis among infants in the United States from the end of the 1970s through the 1990s. In the 1990s, the increase occurred exclusively among infants 4 months or younger and contrasted with the absence of a change in the incidence of reported cases among older infants.

The increase in reported cases of pertussis among young infants may have resulted from several factors, including a real increase in disease, increased awareness of pertussis among clinicians, or improved surveillance activities. We believe that the increase of reported cases among infants reflects a real increase in *B pertussis* disease and is not an artifact from the surveillance system for the following reasons. First, the increase in infant cases was unlikely to have resulted from greater awareness among clinicians. Clinicians, especially pediatricians, have recognized pertussis as a cause of severe respiratory disease among infants for decades. Second, introduction of new case definitions and diagnostic methods contributed little to the increase observed in the data; the specificity of the reported cases, as shown by the proportion of cases confirmed by isolation of *B pertussis*, increased in the 1990s. Third, no great change in the completeness of reporting was detected using as a surrogate the stability of the proportion of reported infant cases who were hospitalized during the 1980s and 1990s, and by a recent analysis of the completeness of reported pertussis deaths. This stability suggests that reporting of milder cases did not increase. Finally, reported cases of pertussis among infants aged 5 to 11 months did not increase in the 1990s; some increase in reported cases among these infants would have been likely if a change had occurred in case ascertainment or reporting.

Increased rates of pertussis among infants resulted in large numbers of excess hospitalizations and deaths because infants have the highest age-specific rates of clinically severe pertussis and its complications. The number of reported pertussis hospitalizations among infants 4 months or younger in the 1990s increased by more than 4500 during the 1980s; reported deaths increased at least by 33. The true increase in pertussis hospitalizations and deaths is probably larger, as previous studies have estimated that only approximately one third of pertussis hospitalizations were reported to the CDC. Severe pertussis and deaths among young infants also may not have been recognized when the clinical presentation of pertussis was atypical. Infants, especially neonates, can present with episodes of apnea and bradycardia, and typical cough can be minimal or absent.

Among infants aged 5 to 11 months, the age-specific incidence of pertussis remained stable. Increased immunization coverage in the 1990s is one likely reason that increased pertussis activity did not cause an increase in reported cases among infants aged 5 to 11 months and young children. In the United States, estimated coverage with 3 doses or more of DTP vaccination improved from less than 68% among children aged 1 to 4 years in the 1980s to greater than 86% by 13 months of age from 1995 to 1999. Infants aged 5 to 6 months may have been too young to have received 3 doses of pertussis vaccine. However, we
believe that the increased level of vaccination coverage with 2 doses of DTP in this age group in the 1990s\textsuperscript{26} resulted in stable rates of pertussis. Our data suggest a protective effect from even 2 doses of DTP in this age group (Table 3), and other reports support this observation.\textsuperscript{28-30}

The Healthy People 2010 initiative of the US Department of Health and Human Services sets a goal for the year 2010 of less than 2000 pertussis cases among children younger than 7 years annually. This goal assumes that “pertussis among children will be reduced by increasing vaccination coverage.”\textsuperscript{31} Our analyses suggest that pertussis is increasing among very young infants despite high rates of immunization among infants and preschool children. Since the youngest infants are not directly protected by immunization using current vaccines and vaccine policies, our analyses suggest that improved implementation of the current vaccination recommendations may not substantially reduce the morbidity and mortality of infant pertussis. New strategies are needed to prevent the morbidity and mortality among infants too young to be fully vaccinated in the United States.

Developing improved control measures for pertussis among infants will require a better understanding of the reasons for the increase in infant pertussis, including the sources of and risk factors for transmission. Increased pertussis among young infants may reflect either decreased immunity to pertussis or increased exposure to \textit{B pertussis} among young infants. Data are limited on hypotheses for the potential of decreased immunity among infants.\textsuperscript{22} Increased exposure of young infants to \textit{B pertussis} may have resulted from increased \textit{B pertussis} circulation among individuals likely to transmit to infants. The most frequent sources for transmission of pertussis to infants appear to vary depending on the level of effective immunization coverage\textsuperscript{33} and possibly other epidemiological factors such as family structure. The majority of infants studied in the United States in the 1990s did not have an identified source; the most frequent identified sources for transmission of pertussis to infants were parents, followed by siblings.\textsuperscript{22,34,35} Similar patterns were observed in the 1990s in other countries with high vaccination coverage.\textsuperscript{33,36,37} The seasonality of pertussis is likely related to patterns of contacts with infectious cases,\textsuperscript{38} and the observed seasonality pattern among the different age groups in the 1990s also may suggest that pertussis transmission to young infants (summer peak) is associated more closely with adults aged older than 20 years and with school-aged children aged 5 to 9 years than with adolescents (fall peak).

Racial and ethnic disparities in infant pertussis appear to exist but are incompletely understood. As noted earlier, although national data were limited, Hispanic infants had an increased incidence of pertussis compared with non-Hispanic infants in states with more complete ethnicity data for pertussis cases. Hispanic infants also accounted for a disproportionate share (31 deaths [33\%]) of 93 pertussis deaths among infants reported to CDC during the 1990s\textsuperscript{22}; data in the 1990s from California, in which detailed case-based information was available for fatal cases, show that the case-fatality ratio for pertussis cases among Hispanic infants was not significantly different from that among non-Hispanics.\textsuperscript{22} These data may suggest an increased incidence of pertussis among Hispanic infants. In the late 1990s, the national immunization coverage with 3 doses or more of DTP vaccines among children of Hispanic ethnicity was very close to that of non-Hispanic children,\textsuperscript{26} but the timeliness of the second and third doses of DTP at the recommended age for Hispanic infants, as well as for African American infants, was delayed compared with non-Hispanic white or Asian/Pacific islanders (Emmanuel Maurice, MS, CDC/National Immunization Program, written communication, April 7, 2003).

It is unclear if this difference in timeliness of vaccination nationally could explain the suspected increased incidence among Hispanic infants in the selected states. Hispanic ethnicity could be a marker for other high-risk factors among infants, such as an increased opportunity for exposure to \textit{B pertussis}. More information on the reasons for the apparent disparities would be useful in improving control strategies.

A limitation of our study is the use of data from a passive surveillance system. The pertussis surveillance relies on the diagnosis of pertussis, which is generally not sensitive, as well as subsequent reporting from health care professionals; as a result, pertussis was likely underreported. Also the completeness of reporting to the surveillance system may vary by reporting units and by year, although there was no apparent factor causing a change in the completeness as a whole during the study period. Despite these limitations, the trends in the reported pertussis incidence among infants should reflect trends in the true incidence as discussed above.

The potential strategies for improved pertussis control among infants include both nonvaccine strategies, such as trying to reduce infant exposure or increase prophylaxis through educational efforts, and vaccine strategies, such as accelerated vaccination of infants through changes in the recommended schedule of current pertussis vaccines or the development of improved vaccines. The use ofacellular pertussis vaccines among adults and older children could potentially become another tool for controlling pertussis among young infants, if vaccines for these age groups become available in the United States. The safety of DTaP vaccine among adolescents and adults has been shown in clinical studies,\textsuperscript{39-41} and such vaccines already have been licensed in some countries.

Whatever strategy is used, the incidence of pertussis among young infants is likely to be a primary marker of a successful intervention and might be less influenced by changes in case ascertainment or reporting than the incidence of pertussis in older age groups. Further improvements in the surveillance of pertussis among young infants and additional data on both transmission sources and risk factors for
pertussis in this age group are needed to guide the development of new pertussis control strategies and to monitor their success.

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REFERENCES

17. Gan VN, Murphy TV. Pertussis in hospitalized children. AJDC. 1990;144:1130-1140.