Objective

In 2010, California experienced the highest number of pertussis cases in >60 years, with >9000 cases, 809 hospitalizations, and 10 deaths. This report provides a descriptive epidemiologic analysis of this epidemic and describes public health mitigation strategies that were used, including expanded pertussis vaccine recommendations.

Study design

Clinical and demographic information were evaluated for all pertussis cases with onset from January 1, 2010, through December 31, 2010, and reported to the California Department of Public Health.

Results

Hispanic infants younger than 6 months had the highest disease rates; all deaths and most hospitalizations occurred in infants younger than 3 months. Most pediatric cases were vaccinated according to national recommendations, although 9% of those aged 6 months to 18 years were completely unvaccinated against pertussis. High disease rates also were observed in fully vaccinated preadolescents, especially 10-year-olds. Mitigation strategies included expanded tetanus, diphtheria, and acellular pertussis vaccine recommendations, public and provider education, distribution of free vaccine for postpartum women and contacts of infants, and clinical guidance on diagnosis and treatment of pertussis in young infants.

Conclusions

Infants too young to be fully vaccinated against pertussis remain at highest risk of severe disease and death. Data are needed to evaluate strategies offering direct protection of this vulnerable population, such as immunization of pregnant women and of newborns. The high rate of disease among preadolescents suggests waning of immunity from the diphtheria, tetanus, and acellular pertussis series; additional studies are warranted to evaluate the efficacy and duration of protection of the diphtheria, tetanus, and acellular pertussis series and the tetanus, diphtheria, and acellular pertussis series. (J Pediatr 2012;161:1091-6).

Pertussis is an endemic, underdiagnosed bacterial respiratory tract infection caused by Bordetella pertussis. The incidence of pertussis is cyclical, with peaks every 2-5 years as the proportion of susceptible people in the population who are immunologically naïve or have lost immunity grows sufficiently large. The incidence of pertussis reported in the United States decreased substantially after extensive childhood immunization, falling from >265 000 cases in 1934 to a nadir of 1010 cases in 1976. Subsequently, the number of reported cases has increased. During the cyclical peak year of 2005, >25 000 cases were reported in the United States, including >3000 cases in California; the California cases included 8 deaths in infants younger than 3 months, of whom 6 were Hispanic.

Possible explanations for the rising incidence of pertussis include large birth cohorts of susceptible infants, the replacement of more reactogenic whole cell vaccines with less effective acellular pertussis vaccines in the 1990s, more rapid waning of immunity conveyed by acellular pertussis vaccines, and increased detection of cases; and increased detection of cases through greater clinician awareness and the availability of more sensitive polymerase chain reaction (PCR) tests for laboratory confirmation. In California, pertussis PCR tests have been used since the 1990s and became the predominant testing method in 2004.

During 2010, >9000 cases of pertussis were reported in California, more cases than in any of the previous 60 years. This report describes the epidemiology of the 2010 pertussis cases and the public health response to the epidemic.
a confirmed case had either (1) a cough illness and a respiratory specimen from which *B. pertussis* was isolated in culture; or (2) a cough illness of at least 2 weeks in duration along with either (i) a respiratory sample from which PCR testing detected *B. pertussis* nucleic acid or (ii) known contact with a case confirmed by either culture or PCR testing. A probable case had a cough illness of at least 2 weeks but was not laboratory-confirmed and not linked epidemiologically to a laboratory-confirmed case. We defined a suspected case as having a cough illness of any duration along with: (1) PCR detection of *B. pertussis*-specific nucleic acid; or (2) direct epidemiologic linkage to a confirmed case and at least 1 of the following: paroxysms of coughing, inspiratory “whoop,” or post-tussive vomiting.

Clinicians and laboratory personnel are required to report pertussis cases in California residents to local public health departments, which investigate cases and describe case demographics, clinical presentation, and risk factors on standardized forms. Surveillance data are collected through a variety of methods, including patient interviews, immunization registry reviews, and laboratory and medical record abstraction. Data were entered into CDPH-maintained databases and analyzed using SAS 9.2 (SAS Institute, Cary, North Carolina). Clinical characteristics, patient demographics, vaccination status, and clinical outcomes were evaluated for all reported cases in the study period. Incidence rates were calculated using projected state population data from the California Department of Finance.

We describe the public health measures implemented by CDPH and other partners for disease mitigation and prevention as well as the expanded vaccine recommendations.

## Results

A total of 9154 pertussis cases in California with onset in 2010 were reported: 5482 (60%) confirmed, 1706 (19%) probable, and 1966 (22%) suspect. Of the confirmed cases, most (82%) were laboratory-confirmed by PCR testing, 6% were confirmed by culture, and the remaining 12% were epidemiologically linked to a laboratory-confirmed case. Of the suspected cases, 88% were confirmed by PCR testing and the remaining were epidemiologically linked to confirmed cases. The majority (56%) of reported patients became ill from June through September 2010; the peak month was July (Figure 1). The reported incidence of cases per 100,000 population was 23.4 statewide but varied from 0-138.4 by county. Incidence was highest among infants younger than 6 months and lowest in adults 19 years of age and older (Figure 2). Relatively high numbers of cases were observed in fully vaccinated older children and adolescents, with the peak at age 10 years; after age 10, the number of cases declined with age and remained low among those aged 14-18 years (Figure 3).

Race and ethnicity information was reported for 8028 (88%) cases. Overall, the incidence per 100,000 population was higher in Hispanics (26.6) and whites (21.0) than in blacks (10.1) and Asian/Pacific Islanders (6.9). Hispanic infants younger than 6 months had the highest case incidence (587.7 per 100,000); however, among young children and adolescents aged 1-18 years, the highest incidence was in whites (70.3) (Figure 2).
A total of 809 (8.8%) patients were hospitalized, of whom 584 (72%) were younger than 6 months and 446 (55%) were younger than 3 months. Sixty-two percent of all 720 infants younger than 3 months were hospitalized; 79% of these with known race and ethnicity were Hispanic. The hospitalization rate among all infants younger than 6 months was 46%; rates were higher among Hispanic (51%) and Asian/Pacific Islander (45%) infants and lower among black (39%) and white (30%) infants. The median age at disease onset among all hospitalized cases was 2.6 months (range <1 month to 92 years), and the median length of stay was 4 days (range 1-48 days). Of 1506 patients reported to have undergone radiography or computed tomography of the chest, 285 (18%) had a diagnosis of pneumonia. Nineteen patients had seizures and 3 had acute encephalopathy.

**Figure 2.** Pertussis incidence by age and race/ethnicity: California, 2010.

**Figure 3.** Number of pediatric pertussis cases (of 58% of cases with complete vaccine history data) by age and vaccination status: California, 2010.
Ten fatal cases were reported, all in infants. Nine were previously healthy infants younger than 2 months at illness onset who had not been immunized against pertussis; 7 of these infants were younger than 6 weeks. The remaining fatality was a 2-month-old infant born prematurely at 28 weeks’ gestational age who had received the first dose of diphtheria, tetanus, and acellular pertussis (DTaP) vaccine 15 days prior to disease onset. Nine of 10 fatalities were Hispanic infants. The case-fatality rate among infants younger than 3 months was 1.3%. Seven infants were brought to medical attention for their pertussis illness at least once prior to the visit that led to hospital admission. Five of these 7 infants had multiple prior medical visits; however, only 1 received macrolide antibiotic therapy for pertussis. All had leukocytosis with a median white blood cell count of 78,200 cells/mm³. All deaths occurred in infants with symptom onset in the first 9 months of 2010 (Figure 1).

Of 4415 (76%) pediatric cases in infants aged 6 months through 18 years with vaccination information, 380 (9%) were completely unvaccinated against pertussis and 1621 (37%) had not received 1 or more recommended pertussis vaccine doses; 745 (46%) of incompletely immunized individuals were 11-18 years old and had not received tetanus, diphtheria, and acellular pertussis (Tdap) vaccine. The remaining 2414 (55%) were reported to be fully immunized for their age; most (66%) of these were children aged 7-10 years who had received 5 prior doses of DTaP but were younger than the recommended age for immunization with Tdap (Figure 3). Among 314 unvaccinated patients aged 6 months to 18 years with known race/ethnicity, 67% were white (31% of all children in California are white).

In response to the epidemic, CDPH created and disseminated educational materials, clinical guidance, and press releases to local public health departments, health care providers, and the public, with the primary goal of preventing severe pertussis in infants. These materials included information for clinicians on rapid diagnosis and treatment of pertussis in young infants.13 In addition to the existing Advisory Committee on Immunization Practices (ACIP) recommendations for pertussis vaccines, CDPH recommended Tdap for adults 64 years of age and older with infant contact, underimmunized children aged 7-9 years (for whom no pertussis-containing vaccines are currently licensed), and pregnant women. CDPH advised that no minimum interval was needed between tetanus-diphtheria and Tdap vaccines. CDPH also provided publicly purchased Tdap at no cost to hospitals, community health centers, and tribal clinics to immunize pregnant and postpartum women and other contacts of newborn infants.

Discussion

More than 9000 cases of pertussis were reported in California during 2010, more than in any year since childhood pertussis vaccines have been in common use.14 Similar to previous reports,15 rates were highest among infants younger than 2 months and remained high until age 6 months, when most infants have received 3 doses of DTaP. The highest rates were observed in Hispanic infants younger than 6 months. A stepwise increase in disease also was observed among children aged 7-10 years who had completed the DTaP series but who had not yet received the Tdap booster recommended at age 11-12 years, suggesting that this age group is susceptible due to waning immunity. The stepwise decrease in cases observed among adolescents aged 11-14 years suggests that the adolescent Tdap recommendation is effective in protecting younger adolescents.

Although Hispanic infants compose 52% of the birth cohort in California, 90% of pertussis-related deaths and 64% of infants younger than 6 months with pertussis were Hispanic. The increased incidence in Hispanic infants has been noted previously,16,17 but its causes are unknown. Despite their increased disease risk during infancy, Hispanic children in California are estimated to have pertussis immunization similar rates as those of white, non-Hispanic children.18 The Hispanic overrepresentation of cases is limited to children younger than 18 months, the age when most children have received protection from 4 doses of DTaP, suggesting a nongenetic cause for the disparity. In general, Hispanic households are larger than non-Hispanic households, and higher rates of pertussis in Hispanic infants might be related to an increased number of contacts, and therefore more opportunities for exposure to pertussis in the household19 or elsewhere.

Almost all severe pertussis disease occurs in infants. Potential strategies for reducing the occurrence of pertussis in infants include immunization of close contacts (“cocooning”), passive or active immunization of infants, and reducing endemic transmission of pertussis by increasing population immunity. Household members most often are the source of transmission of pertussis to infants.20,21 Since 2006, ACIP has recommended cocooning via the provision of Tdap to postpartum mothers and other contacts of young infants. However, a survey conducted by CDPH in April 2010, prior to the distribution of free Tdap vaccine, found that only 59 (23%) of 256 California birth hospitals had policies to offer Tdap to postpartum women (CDPH unpublished data). Even when additional hospitals in California began immunizing postpartum women in 2010, few were able to offer vaccine to other family members in close contact with newborns due to barriers to vaccinating nonpatients (CDPH unpublished data). Cocooning is resource intensive, and data are lacking on its effectiveness.22

Prevention strategies that provide direct protection to young infants such as passive transfer of pertussis antibodies to infants via immunization of pregnant women (as is done to prevent neonatal tetanus and influenza) and immunizing newborn infants (as is done to prevent transmission of hepatitis B virus) may be applicable to pertussis. In July 2010, CDPH recommended the use of Tdap vaccine in pregnant women. In June 2011, ACIP recommended Tdap vaccine after 20 weeks of pregnancy (for those who previously had not received Tdap) to provide primary protection for the mother and transplacental transfer of pertussis antibodies to the infant. The rate of Tdap immunization in pregnant
women and its efficacy in preventing pertussis infection in young infants are not known; studies are needed to demonstrate if this will be an effective strategy and whether pregnant women would need to be vaccinated during every pregnancy. Also under evaluation is immunization of infants at birth, which would still leave newborns vulnerable until protective antibody levels were achieved.\textsuperscript{23}

A fifth dose of DTaP is recommended for children 4-6 years of age, yet relatively high rates of disease were observed in fully vaccinated children and adolescents, especially those 10 years of age. Most (79\%) pertussis cases in children aged 7-10 years with vaccination histories had received the recommended 5 doses of DTaP vaccine, with the fifth dose most often administered around 4 years of age. This suggests that immunity from the fifth DTaP dose may wane prior to administration of the Tdap booster at age 11-12 years; later administration of the fifth DTaP dose during the recommended age interval or earlier administration of the Tdap booster should be considered. Fewer cases were observed in adolescents for whom the Tdap booster is recommended, suggesting that disease incidence among this age group declines as Tdap coverage increases. Only 22\% of 11- to 18-year-old patients with complete vaccination history had received Tdap. Cases are expected to occur in fully vaccinated individuals because the postlicensure efficacy estimates of DTaP and Tdap are 69\%-81\%\textsuperscript{24,25} and 65.6\%-78.0\%\textsuperscript{26,27} respectively. However, additional studies on efficacy, waning of immunity after immunization, and the optimal timing for doses of DTaP and Tdap are warranted to determine how best to protect older children, adolescents, and their vulnerable contacts, such as infant siblings.

Pertussis is almost as infectious as measles with contact case estimates of 12-17 and, similar to measles, sustained population immunity levels of 92\%-95\% may be necessary to halt endemic transmission of pertussis.\textsuperscript{28,29} In California in 2010, it was estimated that 80\% of children aged 19-35 months and 93\% of children aged 4-6 years had received at least 4 doses of DTaP\textsuperscript{30} and that 71\% of California adolescents had received 1 dose of Tdap.\textsuperscript{31} However, only 8.2\% of adults aged 19-64 years nationally had received 1 dose of Tdap.\textsuperscript{32} Unfortunately, unlike measles, neither pertussis immunization nor disease confers lifelong immunity and it will be extremely difficult, if not impossible, to achieve and sustain levels of population immunity high enough to control pertussis using currently available vaccines.

Despite very low Tdap immunization rates among adults, there were few cases reported in this age group. It is likely that the low rate of reported cases of pertussis in adults masks substantial underdiagnosis, whether because of milder symptoms in adults, fewer adults presenting for care, or a lower level of clinical suspicion if adults do come to medical attention.\textsuperscript{33} Limitations of our study included potential misdiagnosis. The cough illnesses of suspected cases without laboratory confirmation may have had other causes besides pertussis. Moreover, falsely positive pertussis PCR results have been described in other settings.\textsuperscript{34} We were not able to measure any contributions to the increase in reported cases due to increased clinician awareness or PCR testing. However, adding a suspect case definition permitted the reporting of fatal cases in patients who did not live long enough to cough for 2 weeks and patients who were not monitored over time to ensure that cough illness duration was sufficient to meet the clinical case definition. This allowed public health departments to focus limited resources on disease prevention and mitigation efforts rather than case follow-up.

Improvements in pertussis immunization levels may help to reduce endemic transmission of pertussis\textsuperscript{35} and reduce the numbers of infected infants. However, without a vaccine that is more efficacious and confers lifelong immunity, pertussis will continue to be a threat to the lives of young infants. In the absence of better vaccines, it is imperative that strategies to protect young infants directly, such as maternal vaccination, be evaluated for effectiveness. In addition, it is critical that providers continue to be vigilant and promptly diagnose and treat young infants with pertussis.

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References


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DTP (DTaP) vaccine, the Lederle whole-cell component DTP vaccine, or DT vaccine. Pediatrics 1998;101:1-11.


