Numerous outbreaks of vaccine-preventable diseases have occurred in the United States during the past several years. These outbreaks have occurred on national, regional, and local levels and have involved large numbers or only relatively small numbers of children, adolescents, and adults.

To gain understanding of the occurrence of vaccine-preventable diseases in the present era, 2 important concepts should be addressed: reproduction number and community (“herd”) immunity. Reproduction number ($R_0$) relates to the transmissibility of a particular pathogen and indicates the number of secondary cases that one infected person would produce in a completely susceptible population. Measles, for example, is an extremely infectious airborne disease with an estimated $R_0$ of 12 to 18.$^{1,3}$

Community immunity describes a condition that occurs when a significant portion of a population (or herd) is immune—either through immunization or previous infection—and provides a measure of protection for individuals who are not immune (Figure, page 54). It is directly related to the $R_0$ as well as the duration of protection following infection or vaccination. The level
of protection conferred to individuals and, by proxy, society, following infection or vaccination varies based on the causative pathogen and the vaccine.

**Pertussis**

Individuals who are infected by or vaccinated against *Bordetella pertussis* only acquire short-term immunity. In addition to the new birth cohort of susceptible infants, there is a gradually increasing cohort of both older children and adults who once again become susceptible to pertussis. Despite high pediatric immunization rates in the United States, pertussis infections continue to occur in unvaccinated, susceptible children as well as in previously vaccinated older children, adolescents, and adults, due to primary vaccine failure and waning immunity.

Pertussis is a markedly different disease than measles and mumps, and it is far more complex. Although it has been known for more than 2 decades that pertussis circulates in adults, this knowledge often has been overlooked. The most important fact is that reported cases of pertussis only represent the tip of the iceberg—*B. pertussis* causes infection and illness in all age groups, from birth through age 90 years or older. Currently, the majority of pertussis cases in adults are not diagnosed despite the fact that they are an important cause of infections in infants.

During the 2010 epidemic in California, more than 9,000 cases of pertussis were reported, which was the highest number of cases reported in the state in more than 60 years. However, it’s possible that during the previous epidemic in 2005, when approximately 3,000 cases were reported, many more cases occurred but were undetected. Reasons for the higher number of cases detected in 2010 may include an increased awareness by the public and clinicians, along with the nearly universal use of polymerase chain reaction (PCR) testing, a diagnostic method that is far more sensitive than traditional culture. In 2004, PCR became the predominant diagnostic method for pertussis in California; in 2005, 66% of laboratory-confirmed cases were diagnosed by this method and by 2010, 94% were confirmed using PCR.

As with any outbreak of a vaccine-preventable disease, the 2010 outbreak in California was caused in part by unvaccinated children; however, the contributions of this group were modest compared with the effects of vaccine failure and waning vaccine-derived immunity. Vaccine failure and waning immunity have always occurred with pertussis, but the effects likely were exaggerated in this epidemic becauseacellular pertussis vaccines, which have been recommended for the entire 5-dose series since 1997, are not as efficacious as the whole-cell vaccines that they replaced and the first generation of children who received only acellular vaccines had reached adolescence. The efficacy of current pertussis vaccines ranges from 60% to 70%, and this protection decreases over time following vaccination. Data from the 2010 California epidemic suggest that this immunity may be waning more quickly than experts previously believed.

Pertussis infection is endemic in both adolescents and adults. Although not widely recognized, pertussis occurred in adults even in the pre-vaccine era. The 2- to 5-year cycles of pertussis epidemics are caused by an accumulation of susceptible children in the population in whom pertussis is more easily recognized. The clinical manifestations of pertussis in older children, adolescents, and adults depend on the time interval since their last exposure to the pathogen. If they are exposed on an annual basis, then they will likely have asymptomatic infections. If a longer period of time has elapsed since their last exposure, then this will lead to waning antibody levels and, therefore, they will have symptomatic pertussis with varying degrees of severity.

Solving the pertussis problem (ie, obtaining sufficient community immunity to interrupt transmission) is complex and currently not possible. Unlike measles, pertussis vaccination or infection does not confer lifelong immunity. Because the *R₀* for pertussis is similar to that for measles, a similar level of community
immunity (ie, >90%) would be necessary to control its transmission. And because pertussis immunity is constantly waning, even if immunization rates greater than 90% could be achieved, it would not be possible to sustain high levels of immunity without regular revaccination. However, revaccinating all adults, even at 10-year intervals, is extremely unlikely because the universal immunization of adults against influenza and pneumococcal disease has not been successful.

A more realistic goal may be to focus on reducing the number of infant infections, because young infants have the most severe disease and comprise most fatal cases. During the 2010 pertussis epidemic, the primary goal of the California Department of Public Health was to prevent infant deaths. Several approaches can be used to reduce the incidence of infections in infants.

Since 2006, “cocooning” has been the recommended approach for the prevention of pertussis in young infants. This strategy involves the vaccination of anyone who will have contact with infants who are not yet old enough to be vaccinated. However, logistically it is difficult to vaccinate all people who might have contact with an infant, and information on the efficacy of this strategy is currently lacking.

One alternate and promising approach is the vaccination of pregnant women, because this method has the potential to provide direct protection to infants. Pertussis antibodies are transplacentally transmitted to the infant and may offer protection until the infant is old enough to be vaccinated. Although it is clear that women who are vaccinated during pregnancy transmit pertussis antibodies to their infants, it has not yet been proven that these antibodies will in fact protect infants from infection. A third strategy is the vaccination of infants at birth. This method offers the potential for from infection. A third strategy is the vaccination of pregnant women, because this method has the potential to provide direct protection to infants. Pertussis antibodies are transplacentally transmitted to the infant and may offer protection until the infant is old enough to be vaccinated.

The current DTaP (diphtheria, tetanus, and acellular pertussis) and Tdap (tetanus, diphtheria, and pertussis) vaccines are less than optimal, so research should be directed toward new vaccines with more antigens and a better balance of those currently included. Alternately, we could return to whole-cell DTwP (diphtheria, tetanus, and pertussis) vaccines in which lipopolysaccharide (LPS) has been attenuated. LPS was the cause of most adverse reactions following DTwP vaccination, but LPS antibodies are likely important for protection. DTaP vaccines are less reactogenic than DTwP vaccines because virtually all LPS has been removed.

**Measles**

Individuals infected with measles generally experience lifelong immunity. In the prevaccine era, approximately 98% of the US population (and other large-population countries) was immune by age 18. As a result, measles outbreaks only involved children and were caused by the annual introduction of a nonimmune birth cohort. The measles vaccine confers lifelong immunity for most recipients; thus, although more than 90% (estimates range from 83% to 95%) of the population must be immune to measles to interrupt transmission, the United States achieved sufficient community immunity for measles to be declared eliminated in 2000.

Unlike pertussis vaccines, measles vaccines are highly efficacious. Two doses of the current vaccine for MMR (measles, mumps, and rubella) confers lifelong immunity to more than 99% of recipients. Nevertheless, measles remains a concern because of travel into the United States from areas where the disease has not been eliminated, which creates opportunities for outbreaks and sustained transmission. Since the elimination of endemic measles transmission in the United States in 2000, a median of 60 measles cases were reported annually between 2001 and 2010. However, 222 cases of measles were reported in 2011, the majority of which were associated with importation. Many of the patients were unvaccinated or had unknown vaccine status. Of note, nearly half of the measles importations in 2011 occurred among individuals who initially were infected in Europe.

Single-dose coverage with the MMR vaccine among US children aged 19 to 35 months has been higher than 90% since 1996; however, many European countries do not have sufficient community immunity to control transmission due to declining MMR immunization rates. Measles was nearly eliminated in much of Europe, but the disease has staged a comeback in recent years because safety concerns have stopped many parents from vaccinating their children. Although reported cases of measles have declined in Europe in 2012, more than 30,000 cases were reported in 2011. Approximately 15,000 measles infections were reported in France alone, including 714 cases with pneumonia, 16 with encephalitis, and 6 measles-related deaths.

Measles will continue to pose a threat to the United States as long as it persists in other countries, particularly because it has never been controlled throughout many regions of Asia and Africa.

Despite the high overall rate of measles immunity in the United States, pockets of under-vaccinated or unvaccinated individuals, along with the increasing rate of school children whose parents apply for personal belief exemptions, present a cause for concern. Over the past decade in California, the overall rate of personal belief exemptions for children in kindergarten has tripled, rising from 0.77% in 2000 to 2.33% in 2010—some schools reported personal belief exemption rates as high as 84% in 2010.

As the cohort of unvaccinated children transitions into adulthood and travels to regions of the world where measles continues to circulate, the importation of the disease back into the United States will perpetuate. Immunization rates in the United States currently are high enough to prevent the sustained transmission of measles when it is reintroduced into the country. But the pockets of under-vaccinated or unvaccinated
individuals pose a threat to those in the community who cannot be vaccinated, such as infants and immunocompromised people. However, if the number of unvaccinated individuals in the United States continues to grow, the country could experience a resurgence of measles similar to that observed in Europe.

We must remember that a resurgence of measles occurred in the United States between 1989 and 1991 that was primarily attributed to low vaccine coverage. During that period, more than 55,000 cases of measles and 123 deaths occurred; 17,000 cases and 70 deaths were reported in the state of California alone.

Mumps

Although mumps has not officially been eliminated in the United States, there appears to be limited endemic transmission. The Re for mumps is estimated to be between 4 and 12, and the level of community immunity needed to interrupt its transmission is estimated at 75% to 92%. The mumps vaccine, however, may not be as efficacious as has been previously estimated; therefore, achieving the elimination of mumps may be more difficult than anticipated.

Post-licensure studies conducted in the United States between 1973 and 1989 determined that the efficacy of a single dose of the MMR vaccine was between 75% and 91%. A study in the United Kingdom reported that the efficacy of 2 doses of the MMR vaccine was 88%. Protection was considered to be long-term; however, outbreaks of mumps recently have occurred among populations in which most people received 2 doses of the MMR vaccine, thus calling into question the long-term effectiveness of the vaccine.

In 2006, the United States experienced a multistate outbreak of mumps that resulted in 6,584 reported cases. This outbreak primarily affected college students in the Midwest, with the highest incidences occurring within dormitories. Studies conducted on the campuses involved in the outbreak found that high rates of 2-dose MMR vaccine coverage were not sufficient to prevent the outbreak. In addition to primary vaccine failure, the protective effect afforded by the vaccine may wane over time.

Another large outbreak occurred in the northeastern United States during 2009 and 2010. The index case was an 11-year-old boy who was infected with mumps in the United Kingdom. There were 3,502 reported cases, primarily within Orthodox Jewish communities in New York, where prolonged, close contact between individuals in congregate settings facilitated its transmission. Among patients for whom vaccination status was reported, 90% had received at least 1 dose of mumps-containing vaccine, whereas 76% had received 2 doses.

In 2011, a mumps outbreak that involved 29 people occurred on a university campus in California. This outbreak was sparked by an unvaccinated student who also had been infected in the United Kingdom. One of the infected individuals had received 1 dose of MMR, 22 had received 2 doses, 2 had been vaccinated with 3 doses of MMR, and 1 was unvaccinated. One person had received a single dose of mumps-rubella vaccine and had documented serologic evidence of prior mumps immunity; 2 of the other infected individuals were unsure of their vaccination status.

Similar to measles, cases of mumps also have increased in frequency throughout Europe, secondary to declining rates of MMR vaccinations. In the United Kingdom, 3,965 cases of laboratory-confirmed mumps were reported by the Health Protection Agency in 2010. As mumps cases continue to be imported, outbreaks are likely to occur in US settings where large numbers of adolescents and young adults have very close and prolonged contact, which facilitates transmission. In the prevaccine era, mumps typically affected young children, a population in which complications are less common. A transition to cases of mumps in older individuals is likely to result in a greater percentage of complicated cases. Although the Centers for Disease Control and Prevention has not yet made this recommendation, a third dose of MMR was implemented in 2010 during outbreaks in both the northeastern United States and in Guam. The additional dose appeared to aid the control of these outbreaks.

Conclusion

Outbreaks of vaccine-preventable diseases are occurring in the United States and will continue as long as these diseases circulate throughout the world. The epidemiology of each vaccine-preventable disease is different and vaccine efficacy varies based on the type of vaccine. Therefore, approaches to prevent and control these outbreaks must differ. Several approaches will be useful in the prevention and control of all vaccine-preventable diseases, including keeping immunization rates high; implementing effective control measures when cases and outbreaks are reported; striving to develop more effective vaccines; and working to reduce the incidence of vaccine-preventable diseases around the world. The expression “it takes a village” was never more apt.

References


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