Individual and Community Risks of Measles and Pertussis Associated With Personal Exemptions to Immunization

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CONTROL OF VACCINE-PREVENTABLE diseases in the United States has been achieved in part by implementation and enforcement of mandatory vaccination for school entrance in every state.1,2 Despite challenges to immunization laws, the courts have upheld such laws, citing the substantial public health benefit afforded to society by vaccination.3 Yet, to address concerns regarding mandatory vaccination, many states allow personal exemptions from vaccination. Religious exemptions are permitted in 48 states and philosophical exemptions in 15 states.4 Exemptions based on medical grounds are allowed in all states.

Multiple reasons exist for which parents choose not to allow their children to be vaccinated.3 One reason that has become prevalent is fear of adverse reactions to vaccination. As the frequency of vaccine-preventable diseases has decreased, fewer persons have ever witnessed a child who is severely ill with a vaccine-preventable disease. As a result, parents today might perceive a greater risk in having their children vaccinated than in not having them vaccinated.6 Despite this belief, some data demonstrate otherwise. A recent study showed that risk of measles infection during 1985-1992 in the United States was, on average, 35 times greater in children with personal exemptions compared with vaccinated children.7 Another review demonstrated that countries that have more active antivaccine movements have higher rates of pertussis than countries where the majority of children are vaccinated.8

Context The risk of vaccine-preventable diseases among children who have philosophical and religious exemptions from immunization has been understudied.

Objectives To evaluate whether personal exemption from immunization is associated with risk of measles and pertussis at individual and community levels.

Design, Setting, and Participants Population-based, retrospective cohort study using data collected on standardized forms regarding all reported measles and pertussis cases among children aged 3 to 18 years in Colorado during 1987-1998.

Main Outcome Measures Relative risk of measles and pertussis among exemptors and vaccinated children; association between incidence rates among vaccinated children and frequency of exemptors in Colorado counties; association between school outbreaks and frequency of exemptors in schools; and risk associated with exposure to an exemptor in measles outbreaks.

Results Exemptors were 22.2 times (95% confidence interval [CI], 15.9-31.1) more likely to acquire measles and 5.9 times (95% CI, 4.2-8.2) more likely to acquire pertussis than vaccinated children. After adjusting for confounders, the frequency of exemptors in a county was associated with the incidence rate of measles (relative risk [RR], 1.6; 95% CI, 1.0-2.4) and pertussis (RR, 1.9; 95% CI, 1.7-2.1) in vaccinated children. Schools with pertussis outbreaks had more exemptors (mean, 4.3% of students) than schools without outbreaks (1.5% of students; P=.001). At least 11% of vaccinated children in measles outbreaks acquired infection through contact with an exemptor.

Conclusions The risk of measles and pertussis is elevated in personal exemptors. Public health personnel should recognize the potential effect of exemptors in outbreaks in their communities, and parents should be made aware of the risks involved in not vaccinating their children.

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Colorado statute allows both religious and philosophical exemptions, and parents can take these exemptions simply by signing a statement that declares they are “an adherent to a religious or personal belief opposed to immunization.” In 1994, the percentage of school-aged children who were unvaccinated as a result of personal exemptions in Colorado was 1.4%, more than twice the national average of 0.6% for the same year.4

The goal of this study was to assess whether individuals and communities experience adverse consequences associated with personal exemptions. In particular, we evaluated risk of measles and pertussis infection associated with personal exemptions among school-aged children in Colorado in 1987-1998.

**METHODS**

**Definitions**

Children aged 3 to 18 years whose parents chose not to allow them to be vaccinated for religious or philosophical reasons are referred to as exemptors. We did not consider medical exemptions to be personal exemptions. Children were considered to be vaccinated if they had received at least 1 measles vaccination or at least 4 pertussis vaccinations. Cases of disease in unvaccinated or incompletely vaccinated children not declared as exemptors were excluded.

**Annual Frequency of Exemptors**

The proportions of children who were exemptors, fully vaccinated, and incompletely vaccinated were available through the results of an annual immunization summary report sent to all Colorado schools, including preschools, that inquired about the number of students who were vaccinated or exemptors. We assessed trends in annual proportions of exemptors by using the χ² test for trend. A random probability sample of public and private schools was audited by epidemiologists from the Colorado Department of Public Health and Environment (CDPHE) to assess accuracy of the school reports.

**Assessment of Individual Risk**

Children aged 3 to 18 years in Colorado represented the cohort from which we retrospectively calculated incidence rates for measles and pertussis. Physicians and clinical laboratories reported all cases to the CDPHE as mandated by state statute. For each case, a case report form was completed by public health nurses from the local health department and reviewed by epidemiologists at the CDPHE. Because of differences in the diagnostic sensitivity of the 2 diseases, the Centers for Disease Control and Prevention (CDC) required states to report confirmed and probable cases of pertussis but to report only confirmed cases of measles; therefore, these same categories of cases were included in this analysis. Cases were defined according to accepted criteria at the time of diagnosis.9,10 Case definitions did not include information on the case-patient’s vaccination status. For both diseases in 1987-1998, case report forms documented patients’ age, county of residence, and vaccination status. Information regarding the reason for lack of vaccination, including exemptions, was collected for measles in 1987-1998 and for pertussis in 1996-1998; therefore, the analysis of incidence rates among individuals included different periods for the 2 diseases.

We divided children into 4 age groups that correspond to school levels: preschool and kindergarten (3-5 years), elementary school (6-10 years), middle school (11-14 years), and high school (15-18 years). We estimated the annual state population of vaccinated and exemptor children by applying the annual proportion of vaccinated and exemptor children from the school immunization summary report to the entire annual state population of the 4 age groups.11

We calculated incidence rates by dividing the total number of cases among exemptors and vaccinated children by the cumulative number of children during the indicated period within each group. We calculated relative risks (RRs) by dividing the average annual incidence rate among exemptors by the rate in vaccinated children.

**Assessment of Community Risk**

**County Level.** We analyzed whether the frequency of exemptors in a county was predictive of the average annual incidence rate for measles and pertussis among vaccinated children in 1987-1998. We performed Poisson regression analysis using average annual county incidence rates among vaccinated children in the county as the outcome variable and percentage of exemptor children in the county as the primary independent variable. The RR was interpreted as the change in incidence rate for each 1% increase in exemptors. For example, an RR of 2.0 would indicate a doubling of the incidence rate for each 1% increase in exemptors.

We adjusted for several potential confounders, including income, educational status, immigrant population, and population density of individual counties, available at the county level from the 1990 US Census. In addition, because of the changing incidence of disease and rates of exemptors during the study period (measles decreased and pertussis increased), we adjusted for the year group of diagnosis; the 1987-1998 period was divided into four 3-year intervals. The average annual county incidence rates during these 4 intervals were used as 4 separate observations per county. Information regarding exemptions at the county level was available only for 1992, 1993, 1996, and 1998. We used data from these 4 years in a linear regression model of the logarithmic transformation of the percentage of exemptors per county to estimate the percentage of exemptors in each county for the midyear of the 4 intervals (ie, 1988, 1991, 1994, and 1997). One sparsely populated county was excluded because of lack of information on the frequency of exemptors. Significant confounders were defined as variables that caused more than a 10% change in the RR.

**School Level.** Case report forms for measles (1987-1998) and pertussis (1996-1998) collected information on...
the transmission setting of the disease. We considered a school-based outbreak as one in which at least 1 vaccinated child acquired infection in a school.

We analyzed whether the probability of having a school-based outbreak could be predicted by the percentage of exemptors in that school during the 1993 school year for measles or the 1996 school year for pertussis. To prevent biases of testing and reporting caused by county-level differences, only schools in counties in which a school-based outbreak occurred were included. Because the percentage of exemptors in schools was a nonparametrically distributed continuous variable, univariate analysis was performed by using the Wilcoxon rank sum test. Multivariate analysis was performed by using logistic regression. We adjusted for several potential confounders: school size, school level, and county in which a school was located. Significant confounders were defined as variables that caused more than a 10% change in the odds ratio.

Outbreaks

Initiation Among Exemptors. Only outbreaks that involved 5 or more individuals (of any age) and that had 2 or more generations were included. Whether the case-patient was part of an outbreak was indicated on the case report forms. We evaluated whether outbreaks began among exemptors and spread to vaccinated persons by comparing the percentage of exemptors in the index and first generation of the outbreak with that of later generations of the outbreak. The reason we combined the index and first generations was that often the index generation involved only 1 person. Later generations were combined because many outbreaks had only 1 generation after the first. The \( \chi^2 \) test with continuity correction was used to compare proportions.

Risk of Exemptors in Outbreaks of Measles. We quantified the contribution of exemptors in measles outbreaks with 5 or more individuals (of any age). The source of exposure was often recorded on the case report forms.

This analysis quantified the percentage of children in an outbreak who contracted measles through contact with an exemptor. This analysis was not possible for pertussis outbreaks because the source of exposure of most pertussis cases was unknown.

RESULTS

Frequency of Personal Exemptions

During 1987-1998, the percentage of philosophical exemptions among school-aged children in Colorado increased from 1.02% to 1.87% (TABLE 1; \( P<.001 \)). Religious exemptions decreased slightly, from 0.23% to 0.19% (\( P<.001 \)). Overall, philosophical exemptions accounted for 87% of all exemptions.

On average, 11% of schools in the state were audited annually. The annual percentages of religious and philosophical exemptions were similar in audited schools and in the annual immunization summary, with the greatest absolute difference in a single year between the 2 being 0.14% for religious exemptions and 0.47% for philosophical exemptions.

Individual Risk

During 1987-1998, 505 confirmed cases of measles were reported in Colorado, with 202 (40%) occurring in children aged 3 to 18 years. Among exemptors, the measles incidence rate was highest among children aged 3 to 10 years, while among vaccinated children, the rate increased with increasing age (TABLE 2). On average, exemptors were 22 times more likely to acquire measles than were vaccinated individuals. The excess risk of measles among exemptors was greatest among children aged 3 to 10 years (RR, 62.0; 95% confidence interval [CI], 39.0-98.6).

During 1996-1998, 1140 confirmed and probable cases of pertussis were reported in Colorado, with 541 (47%) occurring in children aged 3 to 18 years. Among exemptors, the pertussis incidence rate was highest among children aged 3 to 10 years (Table 2). On average, exemptors were 5.9 times more likely to acquire pertussis than were vaccinated children. Excess risk of pertussis among exemptors was greatest among children aged 3 to 10 years (RR, 15.9; 95% CI, 10.8-23.4).

Our calculated risk of pertussis among exemptors was most likely an underestimate of the true amount. Among children with 0 pertussis vaccinations, 43% had an unknown reason for lack of vaccination. Many of these children were likely exemptors. If all these children are considered to be exemptors, the risk of acquiring pertussis among exemptors compared with vaccinated children increased for children aged 3 to 18 years (RR, 10.6; 95% CI, 8.1-13.8) and for children aged 3 to 10 years (RR, 26.1; 95% CI, 18.9-36.0).

Table 1. Number of School-Aged Children (3-18 y) Exempted From Immunization, Colorado, 1987-1998

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Children Assessed</th>
<th>Medical Exemptions, No. (%)</th>
<th>Religious Exemptions, No. (%)</th>
<th>Philosophical Exemptions, No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>588,371</td>
<td>730 (0.12)</td>
<td>1355 (0.23)</td>
<td>6000 (1.02)</td>
</tr>
<tr>
<td>1988</td>
<td>688,770</td>
<td>896 (0.13)</td>
<td>1401 (0.20)</td>
<td>6002 (0.87)</td>
</tr>
<tr>
<td>1989</td>
<td>627,040</td>
<td>708 (0.11)</td>
<td>1330 (0.21)</td>
<td>6061 (0.97)</td>
</tr>
<tr>
<td>1990</td>
<td>667,004</td>
<td>757 (0.11)</td>
<td>1344 (0.20)</td>
<td>7477 (1.12)</td>
</tr>
<tr>
<td>1991</td>
<td>688,928</td>
<td>768 (0.11)</td>
<td>1376 (0.20)</td>
<td>7622 (1.11)</td>
</tr>
<tr>
<td>1992</td>
<td>720,961</td>
<td>708 (0.10)</td>
<td>1274 (0.18)</td>
<td>8586 (1.19)</td>
</tr>
<tr>
<td>1993</td>
<td>750,505</td>
<td>702 (0.09)</td>
<td>1264 (0.18)</td>
<td>9768 (1.30)</td>
</tr>
<tr>
<td>1994</td>
<td>728,119</td>
<td>714 (0.10)</td>
<td>1313 (0.18)</td>
<td>8978 (1.24)</td>
</tr>
<tr>
<td>1995</td>
<td>754,098</td>
<td>762 (0.10)</td>
<td>1288 (0.17)</td>
<td>9610 (1.27)</td>
</tr>
<tr>
<td>1996</td>
<td>672,927</td>
<td>640 (0.10)</td>
<td>1171 (0.17)</td>
<td>9158 (1.36)</td>
</tr>
<tr>
<td>1997</td>
<td>763,323</td>
<td>970 (0.13)</td>
<td>1336 (0.18)</td>
<td>12,412 (1.63)</td>
</tr>
<tr>
<td>1998</td>
<td>749,761</td>
<td>891 (0.12)</td>
<td>1411 (0.19)</td>
<td>13,991 (1.87)</td>
</tr>
</tbody>
</table>

\( P<.001 \) by \( \chi^2 \) test for trend.
Community Risk

County Level. Measles cases were reported in 19 (30%) of 63 Colorado counties. Of these cases, 78% occurred in the 10 counties with a metropolitan area of more than 100,000 persons (approximately 80% of the state population). Adjusting for the year of diagnosis, the overall annual incidence rate of measles among vaccinated children aged 3 to 18 years in a county was significantly associated with the frequency of exemptors in that county (RR, 1.6; 95% CI, 1.0-2.4). This association was significant for children aged 3 to 10 years (RR, 1.8; 95% CI, 1.6-2.0) and 11 to 18 years (RR, 1.8; 95% CI, 1.6-1.9).

School Level. Twenty-two percent of children with measles acquired infection at school; 33% had an unknown transmission setting. Eight school-based outbreaks occurred in 4 counties (5 elementary, 1 middle, and 2 high schools). A total of 672 schools were included in the analysis. Schools with measles outbreaks had more exemptors (median, 1.5%; mean, 2.8%) than schools without measles outbreaks (median, 1.0%; mean, 1.8%), although this difference was not statistically significant (P = .26).

Twenty-one percent of children with pertussis acquired infection at school; 46% had an unknown transmission setting. Seventeen school-based outbreaks occurred in 5 counties (10 elementary, 2 middle, and 5 high schools). A total of 954 schools were included in the analysis. Schools with pertussis outbreaks had more exemptors (median, 1.9%; mean, 4.3%) than schools without pertussis outbreaks (median, 0.7%; mean, 1.5%; P = .001). In logistic regression analysis, for each 1% increase in exemptors in a school, the risk of having a pertussis outbreak increased by 12% (odds ratio, 1.12; 95% CI, 1.05-1.20). School level, size, and county were not significant confounders of this association.

Outbreaks

Initiation Among Exemptors. In the 14 measles outbreaks included in this analysis, 24 (14.5%) of 166 individuals were exemptors in the index and first generations compared with 18 (7.1%) of 254 in later generations (P = .03). In the 12 pertussis outbreaks included in this analysis, 8 (10.3%) of 77 cases occurred among exemptors in the index and first generations compared with 9 (8.4%) of 107 in later generations (P = .84).

Risk of Exemptors in Outbreaks. In the 18 measles outbreaks included in this analysis, 179 cases among children, 45 (25%) were exemptors. Forty-two percent of exemptors contracted measles through contact with another exemptor. Among vaccinated children, 11% contracted measles through contact with an exemptor; this amount is probably an underestimate of the true percentage because 67% of vaccinated children had an unknown exposure source, some of whom probably were exposed to exemptors. The epidemic curve of a 1994 outbreak demonstrates how a cluster of exemptors early in an outbreak can expose other persons, precipitating cases in later generations (FIGURE).12


<table>
<thead>
<tr>
<th>Age Group, y</th>
<th>Exemptors</th>
<th>Vaccinated Children</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total No.</td>
<td>Average Annual</td>
</tr>
<tr>
<td>Total No. of Cases</td>
<td>Population</td>
<td>per 100,000 (95% CI)</td>
</tr>
<tr>
<td>------------------</td>
<td>------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Measles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td>8</td>
<td>1673</td>
</tr>
<tr>
<td>6-10</td>
<td>24</td>
<td>3706</td>
</tr>
<tr>
<td>11-14</td>
<td>11</td>
<td>3286</td>
</tr>
<tr>
<td>15-18</td>
<td>2</td>
<td>2990</td>
</tr>
<tr>
<td>3-18</td>
<td>45</td>
<td>11656</td>
</tr>
<tr>
<td>Pertussis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td>13</td>
<td>2271</td>
</tr>
<tr>
<td>6-10</td>
<td>18</td>
<td>4233</td>
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<tr>
<td>11-14</td>
<td>5</td>
<td>4758</td>
</tr>
<tr>
<td>15-18</td>
<td>0</td>
<td>4529</td>
</tr>
<tr>
<td>3-18</td>
<td>36</td>
<td>15791</td>
</tr>
</tbody>
</table>

*Vaccinated children in the measles analysis received 1 or more measles vaccinations. Vaccinated children in the pertussis analysis received 4 or more pertussis vaccinations. CI indicates confidence interval.
†The annual population of Colorado for all age groups increased during the 12-year period. The cumulative population during the indicated period in each age group was used to calculate incidence rates (see “Methods” section of text).
COMMENT
Our study showed that during a recent decade in Colorado, exemptors were, on average, 22 times more likely to acquire measles and 6 times more likely to acquire pertussis than vaccinated children. In children of day care and primary school age, in whom contact rates and susceptibility are higher, these risks were approximately 62-fold and 16-fold greater among exemptors for measles and pertussis, respectively. Our findings for measles were consistent with a recent report that estimated that exemptors were at a 35-fold increased risk of acquiring measles compared with vaccinated children in the United States overall. That study, like ours, documented that the risk is most elevated for younger children. This could be a result of the natural epidemiology of measles, in which the majority of unvaccinated children are infected before age 10 years. In addition, the rate of measles among vaccinated children increased with age in our study, probably because of primary vaccine failures among older children who were vaccinated before age 15 months in the 1970s.

This is the first study, to our knowledge, to document at the population level that an excess risk of acquiring pertussis exists among exemptors. Similar to measles, risk of pertussis among exemptors was highest in younger children. This could be because the rate of pertussis is highest among young children and immunity due to vaccination wanes approximately 10 years after the last vaccination.

Our study also provides specific evidence suggesting that personal exemptors put vaccinated children at risk of acquiring measles and pertussis. Multiple outbreaks have occurred in isolated religious communities where most children claimed religious exemptions to vaccination. However, our study suggests that when mixing of exemptors and vaccinated populations occurs in a county, in a school, or during an outbreak, exemptors can transmit disease to vaccinated individuals.

Our study had several limitations. For the analysis of individual risk, the vaccination status was unknown for 3% of measles and 9% of pertussis cases. Although this decreases the precision of the study, it would not bias the results unless children with unknown vaccination status were significantly more or less likely to be exemptors. Second, on the school immunization summary report, children were labeled as exemptors if they took an exemption from only 1 vaccine but still received others. Therefore, the population of exemptors at risk might have been overestimated for either the measles or the pertussis analysis of individual risk. This bias, however, would tend to underestimate excess risk of disease among exemptors. Third, the county- and school-level analyses were ecological. Nonetheless, we were able to control for several important potential county-level confounders in these analyses. Fourth, for the analysis of school outbreaks, in many cases the transmission setting of disease was unknown. Most likely, some of these children acquired their disease at school; therefore, some school-based outbreaks were missed. This would decrease the power of the study. However, it should not introduce a bias since the transmission setting of exemptors should have been no more or less likely to have been identified than that of vaccinated children. Last, the possibility exists that children’s vaccination status might have influenced their probability of being diagnosed as a case. There may have been a tendency for clinicians to perform more laboratory tests on unvaccinated children because of a higher suspicion of disease. However, our data did not show significantly more laboratory-confirmed cases among exemptors than among vaccinated children (data not shown). Moreover, this tendency on the clinicians’ part may have been offset by the possibility that parents of exemptors might have been less likely than those of vaccinated children to seek traditional medical care that involved laboratory testing. Public health personnel investigated all reported cases prior to knowing the case-patient’s vaccination status, which was ascertained only after completion of the case report form. When defining a case as confirmed or probable, personnel used the standard definitions established by the CDC, which did not include an individual’s vaccination status.

Although their perspectives might differ, both parents and public health policymakers must balance competing perceptions of risks and benefits in making immunization decisions. The perception of the prevalence and severity of the disease is often weighed against the per-
PERSONAL EXEMPTIONS TO IMMUINIZATION

cieved likelihood of an adverse reaction to vaccination. The success of immunization against vaccine-preventable diseases has shifted the focus of the public’s perception of risk from the diseases to the vaccines themselves. Concerns regarding the safety of the vaccines against measles and pertussis have been raised by some reports from the medical community, although the data often have been misinterpreted and sensationalized when communicated to the public. Despite these reports, studies have proven that risk of serious adverse events to the measles and the whole-cell and acellular pertussis vaccines remains rare.

The decision to forgo vaccination must balance individual rights with social responsibility. If all vaccine-preventable diseases were confined to the individual (eg, tetanus), the consequences of forgoing vaccination would fall only on the child whose parents made the decision. Most vaccine-preventable diseases, however, are spread from person to person. Therefore, the health of any individual in the community is critically dependent on the health of the rest of that community. A single unvaccinated child in a community of vaccinated children holds a strategically opportunistic high ground, protected from risk of disease by herd immunity while avoiding risk of exceedingly rare adverse events associated with vaccination. Yet, when too many parents want their child to be that child, the entire community is affected. Such a situation occurred in both Japan and the United Kingdom in the 1970s, when pertussis vaccine coverage declined from more than 80% to less than 30% after reports of severe adverse reactions to the vaccine, resulting in major nationwide pertussis epidemics. Until vaccines become available that are 100% effective or a disease is eradicated, an increase in exemptions has the potential to precipitate communitywide outbreaks of vaccine-preventable diseases.

Parents making decisions regarding vaccination should understand not only the risks of vaccination but also the risks of not being vaccinated. Enhanced surveillance for vaccine-preventable diseases, particularly pertussis, which is underdiagnosed, and rapid control measures (eg, prophylactic antibiotics for pertussis) might be warranted in areas that have larger populations of personal exemptions. Policymakers might consider requiring some evidence of parental strength of conviction when claiming personal exemptions for their children. In Colorado, the ease of claiming personal exemptions could encourage exemptions of convenience by parents who have not really considered the issue or who want to avoid the financial and time commitment of having their children vaccinated. Health care practitioners and public health officials could do a better job of exchanging useful information with parents, enabling them to understand the benefit of vaccines and to recognize the risks for the diseases they prevent, in the context of what is known regarding risks associated with vaccination. Further studies and interventions should be pursued that will ensure that individual and societal decisions regarding childhood immunizations are made on the basis of information and understanding.

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REFERENCES