Asymptomatic Wild-Type Poliovirus Infection in India among Children with Previous Oral Poliovirus Vaccination

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Background. Mucosal immunity induced by oral poliovirus vaccine (OPV) is imperfect and potentially allows immunized individuals to participate in asymptomatic wild-type poliovirus transmission in settings with efficient fecal–oral transmission of infection.

Methods. We examined the extent of asymptomatic wild-type poliovirus transmission in India by measuring the prevalence of virus in stool samples obtained from 14,005 healthy children who were in contact with 2761 individuals with suspected poliomyelitis reported during the period 2003–2008.

Results. Wild-type poliovirus serotypes 1 and 3 were isolated from the stool samples of 103 (0.74%) and 104 (0.74%) healthy contacts, respectively. Among contacts of individuals with laboratory-confirmed poliomyelitis, 27 (12.7%) of 213 and 29 (13.9%) of 209 had serotypes 1 and 3, respectively, isolated from their stool samples. The odds ratio of excreting serotype 1 wild-type poliovirus was 0.13 (95% confidence interval, 0.02–0.87) among healthy children reporting ≥6 doses of OPV, compared with children reporting 0–2 doses. However, two-thirds of healthy children who excreted this virus reported ≥6 doses, and the prevalence of this virus did not decrease with age over the sampled range.

Conclusions. Although OPV is protective against infection with poliovirus, the majority of healthy contacts who excreted wild-type poliovirus were well vaccinated. This is consistent with a potential role for OPV-vaccinated children in continued wild-type poliovirus transmission and requires further study.

The Global Polio Eradication Initiative (GPEI) has exclusively relied on oral poliovirus vaccine (OPV), rather than inactivated vaccine, primarily because of its superior ability to induce gut mucosal immunity [1–3]. This vaccine mimics natural infection and induces both circulating and secretory antibodies that protect, not just against paralytic disease, but also against infection and transmission of wild-type poliovirus [1]. Use of OPV in routine and mass vaccination activities has been successful in achieving global eradication of serotype 2 wild-type poliovirus, and in 2009, only 4 countries were yet to interrupt indigenous transmission of serotypes 1 and 3. However, persistent transmission in these 4 countries—India, Afghanistan, Pakistan, and Nigeria—has significantly escalated the costs of the eradication program and led to the reintroduction of infection and polio outbreaks in a number of African and Asian countries [2].

Mucosal immunity induced by OPV is not completely protective and may wane over time, such that immunized children may be infected and excrete poliovirus. Challenge studies, during which children who had previously received 2–5 doses of trivalent OPV were fed live-attenuated vaccine virus, have typically found excretion of vaccine virus in 10%–35% of stool sam-

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In northern India, wild-type poliovirus continues to circulate despite high levels of vaccine-induced immunity [12, 13]. The recent report of the Advisory Committee on Polio Eradication highlighted northern India as a unique challenge to the GPEI, compared with other regions where the disease is endemic, where polio persistence is largely the result of poor vaccine coverage [14]. Recent research has demonstrated a significant protective effect of monovalent and trivalent OPV against infection and excretion of vaccine poliovirus after challenge among children in northern India [15]. However, even after 12 or more doses of monovalent type 1 OPV, the odds ratio (OR) for excreting type 1 poliovirus remained at 0.23 (95% confidence interval [CI], 0.15–0.36) for vaccinated children, compared with unvaccinated children, with a mean duration of excretion after challenge of 7 days. Although the titer of excretion among these children is likely to be reduced, compared with that among unvaccinated children, the imperfect nature of gut mucosal immunity to poliovirus means that individuals immunized with OPV could participate in the continued circulation of wild-type poliovirus. A role for fully vaccinated children in the transmission of wild-type poliovirus has previously been suggested to explain the outbreak of poliomyelitis due to serotype 1 in Oman during 1988 [16]. In the highly vaccinated population living in northern India, the potential contribution of vaccinated children to the persistent transmission of wild-type poliovirus warrants investigation.

In this article, we describe the extent of asymptomatic wild-type poliovirus infection among healthy children who have been in contact with individuals with suspected and laboratory-confirmed poliomyelitis reported in India during the period 2003–2008. We discuss the implications of our findings for the global eradication of wild-type poliovirus.

**METHODS**

*Data collection.* We examined wild-type and vaccine (Sabin) poliovirus excretion among healthy contacts of individuals with suspected poliomyelitis reported in India from January 2003 through December 2008. Active surveillance of polio in India requires detailed case investigation of all children <15 years of age with acute flaccid paralysis (AFP), including the collection of 2 stool samples to test for the presence of poliovirus and a follow-up examination 60 days after the onset of paralysis to test for residual weakness [17]. If 2 adequate stool samples (collected at least 24 h apart and within 14 days after the onset of paralysis) are not available, and if the child has suspected poliomyelitis, then a single stool sample is collected from each of 5 healthy children <5 years of age who are likely to have been in close contact with the child with suspected poliomyelitis. Suspected poliomyelitis in children (called “hot” AFP cases) in India are identified by the district immunization officer or surveillance medical officer as those children <5 years of age with either (1) fever at onset of paralysis and asymmetric proximal paralysis or (2) rapidly progressive paralysis leading to bulbar involvement and/or death [18]. Since 2004, if wild-type poliovirus is detected among the stool samples obtained from the healthy contacts, then the suspected case has been defined as confirmed poliomyelitis.

During identification of healthy contacts, an effort was made to include those children with the closest contact to the individual with suspected poliomyelitis, such as siblings, playmates, or residents of the same household. If the individual with suspected poliomyelitis was resident in >1 household during the incubation period, a small number of additional stool samples were collected from that household. Stool samples from healthy contacts were collected as soon as possible and up to 6 months after onset of paralysis in the suspected case patient and were tested for the presence of poliovirus and other enteroviruses. Samples that yielded results positive for poliovirus were investigated by intratypic differentiation tests to determine whether the isolated virus was vaccine-related or wild-type virus [18].

The age, location, and vaccination history of children with AFP and healthy contacts from whom stool samples were collected were recorded through interviews with parents or caregivers.

Institutional ethics approval was not required, because this study is a retrospective analysis of routinely collected surveillance data, free of personally identifiable information, and recording the use of standard vaccines licensed by the National Regulatory Authority of the Government of India.

**Statistical analysis.** The presence of wild-type and vaccine-related polioviruses in the stool of healthy contacts of persons with suspected poliomyelitis was examined as a function of their age and reported number of OPV doses received and was also examined as a function of the age, date of onset of paralysis, and clinical findings at the 60-day follow-up examination of the individual with suspected poliomyelitis.

Among suspected poliomyelitis cases that was subsequently laboratory confirmed through testing of stool samples, the distribution of the number of healthy contacts excreting wild-type poliovirus was also examined. Two parametric models were fit to these data with use of maximum likelihood methods. In the first model, there was a constant probability of excretion among the healthy contacts of each individual with poliomyelitis, and in the second model, the probability of excretion by healthy contacts was assumed to vary among individuals with poliomyelitis according to the beta distribution.

The probability of excretion of wild-type poliovirus as a function of the age of the healthy contact and time since onset of paralysis in the individual with suspected poliomyelitis...
was examined using logistic regression. An interaction term was included to examine the impact of the age of the healthy contact on the timing of wild-type poliovirus isolation with respect to the date of onset of paralysis in the individual with suspected poliomyelitis. The expected proportion of healthy contacts with wild-type poliovirus in their stool samples, based on a simple mathematical model of transmission, was calculated as a function of the time since onset of paralysis in the individual with suspected poliomyelitis and compared with the observed data under the null hypothesis of transmission from the individual with suspected poliomyelitis only and with no secondary transmission among the healthy contacts (see the Appendix, which appears only in the online version of the Journal). By way of comparison, the relationship between the prevalence of wild-type poliovirus excretion in the stool samples of individuals with AFP and the time since onset of paralysis was also examined.

To examine the impact of vaccination on the probability of wild-type poliovirus excretion among healthy contacts, the number of OPV doses among those individuals who excreted wild-type virus was compared with the number reported for the other contacts of the same person with suspected poliomyelitis who did not excrete poliovirus. The probability of excreting serotype 1 or 3 wild-type poliovirus was related to the reported number of doses and the age of the healthy contact with use of conditional logistic regression of the $x:n$ matched case controls, where $x$ and $n$ are the number of healthy contacts of the individual with suspected poliomyelitis with and without wild-type poliovirus in their stool samples, respectively. A matched analysis was necessary to remove confounding between the receipt of OPV and the probability of isolating wild-type poliovirus, which is the result of more-frequent supplementary vaccination activities targeted at areas with persistent wild-type poliovirus transmission. Children with vaccine-related virus isolated from stool samples were excluded from this analysis.

The number of inadequately vaccinated children (i.e., those who reported having received 0–2 doses of OPV) in contact with individuals with laboratory-confirmed poliomyelitis was small. To get an idea of the secondary attack rate among susceptible contacts, the probability of wild-type poliovirus excretion among these children was estimated with use of a likelihood approach based on the observed distribution of excretion by number of OPV doses among contacts of patients with laboratory-confirmed poliomyelitis and the OR of excretion by number of doses estimated from all healthy contact children (see the Appendix, which appears only in the online version of the Journal).

# RESULTS

Stool samples were collected from a total of 14,005 healthy contacts of 2761 individuals with suspected poliomyelitis. Stool samples were collected from exactly 5 healthy contacts for 2571 (93.1%) of the individuals with suspected poliomyelitis, 1–4 contacts for 86 (3.1%) of the individuals with suspected poliomyelitis, and from $\geq$6 contacts for 104 (3.8%) of the individuals with suspected poliomyelitis. Wild-type poliovirus serotypes 1 and 3 were isolated from 103 (0.74%) and 104 (0.74%) of these stool samples, respectively, corresponding to the contacts of 72 (2.6%) and 62 (2.2%) individuals with suspected poliomyelitis, respectively. Excretion of $\geq$1 wild-type poliovirus serotype was not found among these healthy contacts. The majority of wild-type poliovirus isolates were obtained from samples from the states of Uttar Pradesh and Bihar (Table 1). Vaccine poliovirus serotypes 1, 2, and 3 were isolated from the stool samples of 481 (3.4%), 241 (1.7%), and 434 (3.1%) healthy contacts, respectively.

Among individuals with suspected poliomyelitis, 1061 (38.4%) died, 65 (2.4%) were lost to follow-up or had missing follow-up data, 1211 (43.9%) had residual weakness, and the remaining 424 (15.4%) fully recovered. Wild-type poliovirus was more frequently isolated from healthy contacts of individuals with residual paralysis or who had died, compared with healthy contacts of individuals who fully recovered from their AFP ($P = .002$ for serotype 1; $P = .001$ for serotype 3; Table 1).

One or 2 stool samples were collected from 309 (11.2%) and 1579 (57.2%) individuals with suspected poliomyelitis, respectively. Among those with 2 stool samples, at least 1 stool was obtained $\geq$14 days after the onset of paralysis in 1494 (94.6%) of case patients, and in the remaining 85 (5.4%), healthy contacts were sampled despite the collection of 2 adequate stool samples within 14 days. Among all individuals with suspected poliomyelitis, 480 (17.4%) had at least 1 stool sample taken within 14 days of the onset of paralysis. Absence of wild-type poliovirus in stool samples obtained within 14 days of the onset of paralysis in individuals with suspected poliomyelitis was associated with a lower probability of virus isolation among healthy contacts, compared with contacts of individuals with suspected poliomyelitis for whom stool samples were not available within this period ($P = .022$ for serotype 1; $P < .001$ for serotype 3; Table 1).

Wild-type poliovirus serotype 1 was isolated from at least 1 stool sample from 42 individuals with suspected poliomyelitis, and serotype 3 was isolated from 42 individuals with suspected poliomyelitis (1 individual excreted both serotypes and was retained in the independent analyses of excretion of each serotype among the healthy contacts). Among the healthy contacts of these individuals with laboratory-confirmed poliomyelitis, 27 (12.7%) of 213 and 29 (13.9%) of 209 had wild-type poliovirus serotype 1 and 3, respectively, isolated from their stool samples; these proportions increased to 19 (18.6%) of 102 and 19 (21.1%) of 90, respectively, for those sampled within 3 weeks of the onset of paralysis in the individual with po-
Table 1. Proportion of Healthy Contacts with Wild-Type Poliovirus in Stool Specimens according to Location and Characteristics of the Individual with Suspected Poliomyelitis

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of subjects</th>
<th>No. (%) of subjects with positive results, by serotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Serotype 1</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>5737</td>
<td>67 (1.17)</td>
</tr>
<tr>
<td>Bihar</td>
<td>3895</td>
<td>27 (0.69)</td>
</tr>
<tr>
<td>Other</td>
<td>4373</td>
<td>9 (0.21)</td>
</tr>
<tr>
<td><strong>Sixty-day investigation of subject with suspected poliomyelitis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual weakness</td>
<td>6134</td>
<td>48 (0.78)</td>
</tr>
<tr>
<td>No residual weakness</td>
<td>2154</td>
<td>6 (0.28)</td>
</tr>
<tr>
<td>Lost to follow up</td>
<td>14</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Died</td>
<td>5409</td>
<td>48 (0.89)</td>
</tr>
<tr>
<td>Missing data</td>
<td>294</td>
<td>1 (0.34)</td>
</tr>
<tr>
<td><strong>Result of stool sample collection from subject with suspected poliomyelitis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wild-type poliovirus isolated from at least 1 stool sample</td>
<td>213</td>
<td>27 (12.7)</td>
</tr>
<tr>
<td>Wild-type poliovirus not detected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One or 2 stool samples collected, at least 1 within 14 days of onset of paralysis</td>
<td>2053</td>
<td>5 (0.24)</td>
</tr>
<tr>
<td>One or 2 stool samples collected, none within 14 days of onset of paralysis</td>
<td>7289</td>
<td>34 (0.47)</td>
</tr>
<tr>
<td>No stool samples collected</td>
<td>4450</td>
<td>37 (0.83)</td>
</tr>
<tr>
<td>Overall</td>
<td>14,005</td>
<td>103 (0.74)</td>
</tr>
</tbody>
</table>

The proportion of healthy contacts who excreted wild-type poliovirus did not show significant variation according to how soon the confirmatory stool sample was obtained from the person with poliomyelitis after the onset of paralysis (data not shown). The distribution of the numbers of healthy contacts of individuals with laboratory-confirmed poliomyelitis excreting wild-type poliovirus is shown in Figure 1. Seventeen (40%) and 16 (38%) of individuals with laboratory-confirmed poliomyelitis had ≥1 healthy contact with a stool sample positive for wild-type poliovirus serotype 1 or 3, respectively, indicating that the sensitivity of the approach of sampling 5 healthy contacts to detect poliomyelitis among individuals with “hot” AFP cases is ~40%. A model with a variable probability of excretion among the healthy contacts of each individual with laboratory-confirmed poliomyelitis showed a significantly better fit to the data than did a model with a constant probability (likelihood ratio test, $P = .03$ and $P = .001$ for serotypes 1 and 3, respectively).

A total of 12,675 (90.5%) of the healthy contacts had complete data on age, and 10,775 (76.9%) had complete data on the number of OPV doses received. In agreement with surveillance guidelines, 11,968 (94.4%) of the healthy contacts with complete age data were <5 years of age (and 12,578 [99.2%] were <6 years of age). Excretion of wild-type poliovirus serotype 1 did not decrease with age over the sampled range, in contrast with the age distribution of individuals with suspected poliomyelitis that were subsequently confirmed through isolation of wild-type poliovirus from one of their healthy contacts (Figure 2). This also appears to be the case for serotype 3, although the difference is much less apparent. The age distribution of excretion among healthy contacts did not vary according to whether the individual with suspected poliomyelitis had negative stool samples collected within 14 days of the onset of paralysis or whether the suspected case was subsequently laboratory confirmed (data not shown).

Most children reported receiving >10 doses of OPV, and a crude comparison of the number of doses reported for children with and children without wild-type poliovirus in their stool samples did not reveal a consistent pattern (Table 2). The case-control analysis of the protective efficacy of OPV against wild-type poliovirus excretion resulted in the matching of 86 and 88 healthy children excreting wild-type poliovirus serotypes 1 and 3, respectively, with 344 and 269 control children in contact with the same individuals with suspected poliomyelitis (Figure A1). In this matched analysis, with age included as a categorical variable (6-month age groups), there was a significant reduction in the OR of excreting serotype 1 wild-type poliovirus among children reported to have received ≥6 doses of OPV, compared with that for children who received 0–2 doses (OR, 0.13; 95% CI, 0.02–0.87). There was also a statistically nonsignificant reduction among children reported to have received 3–5 doses of OPV (OR, 0.35; 95% CI, 0.07–1.67). The odds of excretion of serotype 3 wild-type poliovirus did not decrease after receipt of OPV, presumably because of the use of monovalent type 1 OPV during the majority of supplementary immunization activities in India during 2006–2008 and, as a consequence, the
infrequent receipt of doses containing serotype 3 among these children [19].

Based on the estimated odds of wild-type poliovirus excretion among healthy children with different numbers of OPV doses and on the observed distribution by dose number of excretion among contacts of individuals with laboratory-confirmed poliomyelitis, the maximum likelihood estimate of the probability of detecting serotype 1 wild-type poliovirus among stool samples taken from inadequately vaccinated children (ie, those who received 0–2 doses) in contact with individuals with serotype 1 poliomyelitis was 0.51 (95% CI, 0.16–0.84). The same analysis gives a probability of excretion among contact children reporting  6 doses of 0.12 (95% CI, 0.08–0.16).

The probability of wild-type poliovirus excretion among healthy contacts decreased significantly in the second week after the onset of paralysis in individuals with suspected poliomyelitis, compared with the first week (P < .001 for serotypes 1 and 3), but then continued at appreciable levels up to ~3 months later (Figure 3). The prevalence of excretion among stool samples from individuals with AFP decreased somewhat more steeply with time since the onset of paralysis. The probability of detecting wild-type poliovirus as a function of time since onset of paralysis in the individual with suspected poliomyelitis did not depend on the age of the healthy child (ie, they were nonsignificant interaction terms in the logistic regression).

The patterns of wild-type poliovirus excretion among healthy contacts over time were in broad agreement with expectations based on the null hypothesis of transmission from only the individual with suspected poliomyelitis (Figure 3). The maximum likelihood model in which the individual with suspected poliomyelitis remained infectious after the onset of paralysis provided a significantly better fit to the data than did the model in which infectiousness ceased after the onset of paralysis (log-likelihoods of −597.6 and −608.4 for serotypes 1 and 3, respectively, compared with −741.7 and −760.0). The maximum likelihood estimate of the mean duration of wild-type poliovirus excretion by the healthy contact under this model was 11 days for serotype 1 and 12 days for serotypes 3.

**DISCUSSION**

Healthy children who were in contact with children with laboratory-confirmed poliomyelitis had detectable wild-type poliovirus in their stool sample in 13% of cases, increasing to 20% for samples obtained within 3 weeks of the onset of paralysis in the child with poliomyelitis. Prior vaccination with OPV was found to be protective against asymptomatic infection and excretion of serotype 1 wild-type poliovirus. The development of significant protective gut mucosal immunity following vaccination with OPV is in agreement with studies of vaccine poliovirus excretion after challenge with the live-attenuated OPV among children in the same setting [15]. Despite this protective effect, 15% of children who reported receipt of  10 doses of OPV and who were in contact with individuals with laboratory-confirmed cases of poliomyelitis had serotype 1 wild-type poliovirus isolated from their stool samples, which is consistent with the imperfect nature of gut mucosal immunity (Table 2).

The estimated probability of detecting serotype 1 wild-type poliovirus among inadequately vaccinated children (ie, those who had received 0–2 OPV doses) in contact with children with poliomyelitis was ~50%, based on the maximum likeli
Figure 2. Fraction of healthy contacts of individuals with suspected poliomyelitis with (A) serotype 1 and (B) serotype 3 wild-type poliovirus isolated from their stool samples, by 6-month age group and the age distribution of individuals with suspected poliomyelitis where (C) serotype 1 and (D) serotype 3 wild-type poliovirus was isolated from at least 1 of their healthy contacts. The error bars in A and B indicate 95% confidence intervals, and the number of healthy children from whom a stool sample was obtained is given for each age category above the bar.

Table 2. No. (%) of Healthy Contacts with Wild-Type Poliovirus Present or Absent in Stool Samples, by Reported No. of Doses of Oral Poliovirus Vaccine Received

<table>
<thead>
<tr>
<th>No. of doses</th>
<th>All contacts, by serotype</th>
<th>Contacts of subject with laboratory-confirmed poliomyelitis, by serotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Serotype 1</td>
<td>Serotype 3</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>0–2</td>
<td>475 (3)</td>
<td>6 (6)</td>
</tr>
<tr>
<td>3–5</td>
<td>1513 (11)</td>
<td>14 (14)</td>
</tr>
<tr>
<td>6–9</td>
<td>2511 (18)</td>
<td>12 (12)</td>
</tr>
<tr>
<td>&gt;10</td>
<td>6188 (45)</td>
<td>55 (53)</td>
</tr>
<tr>
<td>Missing</td>
<td>3215 (23)</td>
<td>16 (16)</td>
</tr>
<tr>
<td>Total</td>
<td>13902 (100)</td>
<td>103 (100)</td>
</tr>
</tbody>
</table>

hood analysis. The actual number of asymptomatic poliovirus infections among these children is likely to be significantly higher, because not all of those infected would have had detectable virus in their stool at the time of sample collection. In the classic study of wild-type poliovirus circulation among households in Louisiana during 1954–1955, infection (defined as an increase in serum antibody titer) was identified in 37 (37%) of 101 children with natural homologous immunity in contact with individuals with poliomyelitis, and wild-type poliovirus was isolated from single stool specimens in 3 (10%) of 30 contact children sampled [20]. Our findings are therefore consistent with a high secondary attack rate among unvaccinated close contacts of individuals with serotype 1 poliomyelitis in India (likely to significantly exceed 50%), which is consistent with highly efficient transmission of wild-type poliovirus in this setting.
Figure 3. Percentage of healthy children with (A) serotype 1 and (B) serotype 3 wild-type poliovirus isolated from their stool samples, by time since the date of onset of paralysis in the index subject with suspected poliomyelitis, and the percentage of children with suspected poliomyelitis with (C) serotype 1 and (D) serotype 3 wild-type poliovirus isolated from their first stool sample, by time since onset of paralysis (bars). The error bars indicate 95% confidence intervals, and the dashed lines indicate error bars that extend beyond the upper limit of the y-axis. The number of children from whom a stool sample was obtained is given for each time category. The expected fraction of healthy children who excreted wild-type poliovirus, assuming transmission from the index case of acute flaccid paralysis (AFP) only and no secondary transmission among healthy contacts, is shown in A and B for the maximum likelihood model (solid lines; for details of the calculation, see the Appendix, which appears only in the online version of the Journal). The expected percentage of individuals with AFP excreting wild-type poliovirus is shown in C and D (solid lines), based on a mean duration of excretion after the onset of paralysis in the index case of 31 days, in agreement with published data [20, 23–26].

The estimate of the protective effect of OPV against excretion of wild-type poliovirus is imprecise owing to the small number of healthy children excreting this virus (because most suspected cases of AFP are unlikely to be poliomyelitis). In addition, the accuracy of the estimate could be affected by incorrect reporting of the number of OPV doses or differences in exposure between healthy contacts excreting poliovirus and their controls, as discussed elsewhere [12]. Despite these limitations, it is clear that OPV is protective against asymptomatic infection with wild-type poliovirus in India but that this protection is incomplete. This results in continued excretion of wild-type poliovirus among older, OPV-vaccinated children, such that the preva-
lence of wild-type poliovirus isolation among healthy contacts does not decrease with the age of the child over the sampled range. This contrasts with the age distribution of individuals with suspected poliomyelitis for whom wild-type poliovirus was isolated from their healthy contacts (Figure 2) and with the age distribution of all individuals with poliomyelitis reported over the same period (85% of whom were <3 years of age; data not shown).

The continued excretion of wild-type poliovirus among older, OPV-vaccinated children is consistent with a potential role for these children in the asymptomatic transmission of wild-type poliovirus in northern India, where most children have received multiple doses of OPV. The extent of their involvement is likely to be limited by the reduced duration and amount of virus excreted by these children, compared with unvaccinated children [3, 10]. The median human infectious dose for wild-type poliovirus is, however, very low [21], and the extent to which a reduction in the amount of virus excreted translates into a reduction in infectiousness to household and community contacts in this setting is unknown.

Vaccination of a population with OPV protects even unvaccinated children by limiting their exposure to infection (an effect to be distinguished from secondary transmission of vaccine virus, which can immunize some unvaccinated children [11]). This so-called herd immunity allows elimination of wild-type poliovirus from populations without the need to achieve 100% vaccination coverage. Asymptomatic wild-type poliovirus transmission among vaccinated individuals, who are completely protected against paralysis but not against infection, would limit herd immunity and potentially require alternative vaccination strategies [22]. This study demonstrates that a substantial proportion of OPV-vaccinated contacts of individuals with poliomyelitis in India excrete wild-type poliovirus. Additional studies are required to determine the extent to which such OPV-vaccinated children participate in the ongoing transmission of wild-type poliovirus in highly immunized populations and to assess the potential contribution of waning of mucosal immunity. These could include OPV challenge studies to estimate the extent to which mucosal immunity may wane over time and more detailed surveys among household and community contacts of individuals with confirmed poliomyelitis, including children >5 years of age, to measure viral load in their stool and pharynx. If these studies demonstrate significant waning mucosal immunity and that OPV-vaccinated children participate in the circulation of wild-type poliovirus in northern India, strategies to boost their mucosal immunity may be required.

Acknowledgments

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