Timeliness of Childhood Vaccinations in the United States
Days Undervaccinated and Number of Vaccines Delayed

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THE STANDARD MEASURE OF VACCINATION coverage is the percentage of children who have accumulated the required number of vaccine doses, without regard to timing of the vaccinations. However, to maximize protection from vaccine-preventable diseases, the recommended childhood immunization schedule specifies ages at which each of the approximately 20 vaccinations should be administered during the first 18 months of life.1

Remaining appropriately vaccinated at all times decreases a child's risk of contracting vaccine-preventable diseases and prevents disease outbreaks.2,3 Previous studies that examined timeliness of vaccinations have been limited in scope.4-20 A more extensive national study published in 2002 found that 18% of children received all vaccinations at the recommended times or acceptably early (ie, within minimum age allowances) and only 9% at the recommended ages.21 However, this study did not examine the degree of delay, such as duration of time that children were undervaccinated or the number of vaccines delayed.

In this study, we examine timeliness of receipt of vaccination among a nationally representative sample of children in the United States for each recommended vaccine and for all vaccines combined. We evaluate the cumulative number of days children were undervaccinated and the number of vaccines delayed.

Context Only 18% of children in the United States receive all vaccinations at the recommended times or acceptably early.

Objective To determine the extent of delay of vaccination during the first 24 months of life.

Design, Setting, and Participants The 2003 National Immunization Survey was conducted by random-digit dialing of households and mailings to vaccination providers to estimate vaccination coverage rates for US children aged 19 to 35 months. Data for this study were limited to 14 810 children aged 24 to 35 months.

Main Outcome Measures Cumulative days undervaccinated during the first 24 months of life for each of 6 vaccines (diphtheria and tetanus toxoids and acellular pertussis; poliovirus; measles, mumps, and rubella; Haemophilus influenzae type b; hepatitis B; and varicella) and all vaccines combined, number of late vaccines, and risk factors for severe delay of vaccination.

Results Children were undervaccinated a mean of 172 days (median, 126 days) for all vaccines combined during their first 24 months of life. Approximately 34% were undervaccinated for less than 1 month and 29% for 1 to 6 months, while 37% were undervaccinated for more than 6 months. Vaccine-specific undervaccination of more than 6 months ranged from 9% for poliovirus vaccine to 21% for Haemophilus influenzae type b vaccine. An estimated 25% of children had delays in receipt of 4 or more of the 6 vaccines. Approximately 21% of children were severely delayed (undervaccinated for more than 6 months and for ≥4 vaccines). Factors associated with severe delay included having a mother who was unmarried or who did not have a college degree, living in a household with 2 or more children, being non-Hispanic black, having 2 or more vaccination providers, and using public vaccination provider(s).

Conclusions More than 1 in 3 children were undervaccinated for more than 6 months during their first 24 months of life and 1 in 4 children were delayed for at least 4 vaccines. Standard measures of vaccination coverage mask substantial shortfalls in ensuring that recommendations are followed regarding age at vaccination throughout the first 24 months of life.

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spent undervaccinated during the first 24 months of life, the number of late vaccinations, risk factors for severe delay, and the relationship between delay and traditional estimates of vaccination coverage.

**METHODS**

**National Immunization Survey**

We analyzed data from the 2003 National Immunization Survey (NIS), which was conducted by the Centers for Disease Control and Prevention to estimate vaccination coverage rates for US children aged 19 to 35 months. The NIS uses random-digit dialing to survey households with age-eligible children, followed by a survey mailed to the children’s vaccination providers to validate vaccination information. The caregiver provided verbal consent for participation. The NIS was approved by the Centers for Disease Control and Prevention’s institutional review board and the current study was approved by the National Immunization Program, Centers for Disease Control and Prevention.

This analysis is based on children with a completed interview (89% of households identified with an age-eligible child) and adequate vaccination history information from the vaccination provider(s) (69% of children with a completed interview). We further restricted our analysis to children who were at least 2 years old at the time of the interview with the caregiver (70%) to assess vaccinations received during the first 24 months of life. In total, we analyzed data for 14810 children aged 24 to 33 months.

**Vaccination Recommendations**

Vaccination doses routinely recommended in early childhood by the Advisory Committee on Immunization Practices, the American Academy of Pediatrics, the American Academy of Family Physicians include 4 doses of diphtheria and tetanus toxoids and acellular pertussis vaccine (DTaP); 3 doses of poliovirus vaccine; 1 dose of measles, mumps, and rubella vaccine (MMR); 3 or 4 doses (depending on vaccine manufacturer) of Haemophilus influenzae type b vaccine (Hib); 3 doses of hepatitis B vaccine; and 1 dose of varicella vaccine. Pneumococcal conjugate vaccine and influenza vaccine also are recommended routinely during early childhood; however, because recommendations for their use are relatively new and coverage has not yet reached levels of other recommended childhood vaccines, they are not included in this analysis. For simplicity, single-disease (poliovirus, Hib, hepatitis B, and varicella) and standard combined-disease formulations (DTAP and MMR) are referred to as “vaccines” throughout this report.

We analyzed receipt of vaccines according to the harmonized schedule approved by the Advisory Committee on Immunization Practices, the American Academy of Pediatrics, and the American Academy of Family Physicians, which includes recommended ages and age ranges for routine administration, minimum ages at which doses are considered valid, and minimum intervals between doses within a series (Table 1). We excluded vaccine doses that were administered invalidly early, which was defined by the Advisory Committee on Immunization Practices as a dose administered prior to 4 days before the minimum acceptable age or interval.

**Outcomes Measured**

For each day during the first 24 months of life for each child in the survey, we determined vaccination status for each recommended vaccine. Vaccination dates and birth date were used to determine age at vaccination. Age recommendations given in months and weeks

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**Table 1. Recommended and Minimum Ages for Early Childhood Vaccinations**

<table>
<thead>
<tr>
<th>Vaccination Dose</th>
<th>Recommended Age for Routine Administration, mo</th>
<th>Minimum Acceptable Age†</th>
<th>Minimum Acceptable Interval Between Doses‡</th>
<th>Age in Days When Delay Count Initiated§</th>
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<tbody>
<tr>
<td><strong>Hepatitis B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-2</td>
<td>Birth</td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>1-4</td>
<td>4 wk</td>
<td></td>
<td>154</td>
</tr>
<tr>
<td>3</td>
<td>6-18</td>
<td>6 mo</td>
<td></td>
<td>580</td>
</tr>
<tr>
<td><strong>Diphtheria and tetanus toxoids and acellular pertussis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6 wk</td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>10 wk</td>
<td></td>
<td>154</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>14 wk</td>
<td></td>
<td>215</td>
</tr>
<tr>
<td>4</td>
<td>15-18</td>
<td>12 mo</td>
<td></td>
<td>580</td>
</tr>
<tr>
<td><strong>Haemophilus influenzae type b</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6 wk</td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>10 wk</td>
<td></td>
<td>154</td>
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<tr>
<td>3</td>
<td>6</td>
<td>14 wk</td>
<td></td>
<td>215</td>
</tr>
<tr>
<td>4</td>
<td>12-15</td>
<td>12 mo</td>
<td></td>
<td>489</td>
</tr>
<tr>
<td><strong>Poliovirus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6 wk</td>
<td></td>
<td>93</td>
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<tr>
<td>2</td>
<td>4</td>
<td>10 wk</td>
<td></td>
<td>154</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>14 wk</td>
<td></td>
<td>580</td>
</tr>
<tr>
<td><strong>Measles, mumps, and rubella</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>12-15</td>
<td>12 mo</td>
<td></td>
<td>489</td>
</tr>
<tr>
<td><strong>Varicella</strong>¶</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>12-18</td>
<td>12 mo</td>
<td></td>
<td>580</td>
</tr>
</tbody>
</table>

*Approved by the Advisory Committee on Immunization Practices, the American Academy of Pediatrics, and the American Academy of Family Physicians. See also http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5301-immunization1.htm.

†Doses given within 4 days before the minimum age for all vaccines are considered acceptable.

‡Minimum acceptable interval since previous dose in the series. Doses given within 4 days before the minimum interval are considered acceptable.

§Maximum number of days after which the recommended period ends. In most cases, 4 doses of vaccine are recommended. However, the 6-month dose is not required if conjugate vaccine (meningococcal protein conjugate PedvaxHIB or ComVax Merck) is used for the 2- and 4-month doses.

¶Recommended at any visit on or after the first birthday for susceptible children (ie, children who lack a reliable history of chickenpox as judged by a clinician and who have not been immunized).
TIMELINESS OF CHILDHOOD VACCINES

were converted to days. We considered each recommended age to end at the greatest number of days that could compose the given number of months (Table 1). For example, the recommended age of 2 months ends when the child turns 3 months old at 90 to 92 days. For this analysis, a child was considered undervaccinated at 93 days if he/she had not received 1 or more of the doses recommended at 2 months of age.

Days during which the child was undervaccinated for each specific dose accumulated until the child was vaccinated or reached 24 months of age. Days of undervaccination for multidose vaccines were calculated by summing all days during which the child was undervaccinated for 1 or more doses of the respective vaccine. For example, suppose a child started the DTaP series late at age 165 days (5½ months), received the second dose at age 210 days (7 months), the third dose at age 270 days (9 months), and the fourth dose on schedule at 550 days (18 months). The child is considered undervaccinated for dose 1 on days 93 to 164, for dose 2 on days 154 to 209, and for dose 3 on days 215 to 269. Days in overlapping periods of undervaccination (days 154-164) are only counted once, so the child would be considered undervaccinated for DTaP for a total of 172 days (days 93-209 and days 215-269).

When a vaccine dose is given so late that the next dose in the series cannot be given during the routinely recommended time frame, a catch-up schedule is used that specifies minimum intervals between catch-up doses. For our primary analysis described above, all days during which a child was not vaccinated as routinely recommended were counted as undervaccinated. However, we also explored the impact of not counting days during these required intervals. While children are still underprotected during the required catch-up intervals, this more lenient outcome measure accounts for the fact that the subsequent dose is not yet due. For DTaP, a 28-day interval is required between doses 1 and 2 and doses 2 and 3. Thus, in the above example, the child would be considered undervaccinated by this more lenient definition on days 93 to 164 for dose 1, days 193 to 209 for dose 2, and days 239 to 269 for dose 3, for a total of 120 days.

Days undervaccinated for the complete vaccine series were calculated by summing all days during which the child was undervaccinated for 1 or more doses of any vaccine(s). Because periods of undervaccination for different vaccines and doses may overlap, the total number of days undervaccinated may be less than the sum of the vaccine- and dose-specific days.

For each vaccine and for all vaccines combined, we report the mean number of days that children were undervaccinated during the first 24 months of life. We report the percentage of children who were delayed 0 days, 1 to 7 days, 8 to 31 days, 1 to 2 months, 3 to 6 months, 7 to 12 months, or more than 12 months. We also examined the number of vaccines for which children were delayed. We further examined children who were severely delayed in their vaccinations, which we defined as being undervaccinated for more than 6 months and delayed for 4 or more of the 6 vaccines.

To illustrate differences between these measures of timeliness and standard measures of vaccination status, we examined the relationship between delay and up-to-date status at the time of interview as well as up-to-date status at 24 months of age. For a child to be considered up-to-date, he/she must have received all doses of vaccines recommended at 24 months of age. For children who received fewer than 3 doses, undervaccination recommendations were incorporated in this analysis. First, children who receive the first dose of Hib vaccine after 6 months of age need fewer Hib doses; thus, fewer doses were required for these children to be considered completely vaccinated.

Several complexities of the vaccination recommendations were incorporated in this analysis. First, children who receive the first dose of Hib vaccine after 6 months of age need fewer Hib doses; thus, fewer doses were required for these children to be considered completely vaccinated. Second, necessity of the 6-month dose of Hib vaccine depends on the manufacturer of the doses given at ages 2 and 4 months. Because the NIS does not collect manufacturer information, lenient assumptions were made regarding the need for the 6-month dose, as previously described. In brief, children who received 4 doses were assumed to be following the 4-dose schedule (ie, to need a dose at 6 months), while children who received fewer than 3 doses were assumed to be following the 3-dose schedule. For children who received 3 doses, need for the 6-month dose was assessed based on the timing of the third dose. Finally, because varicella vaccination is not required for children with natural immunity, we considered varicella vaccination to be satisfied by either administration of the vaccine or reported chickenpox disease.

To identify factors associated with severe delay of vaccination, characteristics of the child, mother, and immunization providers were evaluated: caregiver-reported race/ethnicity of the child (based on standard options); number of children in the household; mother’s marital status, age, and education level; family poverty status; and number of responding providers and their facility types (public, private, or other/mixed).

Analysis

Estimates of percentages, means, odds ratios, and SEs were calculated using
SUDAAN statistical software (version 8.0, Research Triangle Institute, Research Triangle Park, NC).29 Bivariate analysis and factor-level χ² tests were conducted to assess risk factors for severe delay of vaccinations in early childhood. The level of significance was set a priori at .05. To assess simultaneous contributions of each factor on risk of severe delay, we constructed multivariate logistic regression models with children who were least likely to be severely delayed in the bivariate analysis serving as the reference group for each factor. We conducted standard backward elimination, removing variables in the model until all remaining factors had P values of less than .10, to arrive at a final main-effects model describing factors associated with severe delay. All analyses were weighted to account for the complex sampling design of the NIS.22

RESULTS

Complete Vaccination Series

Children were undervaccinated a mean of 172 days (median, 126 days) cumulatively during the first 24 months of life (Table 2). Approximately 74% of children were delayed for 1 or more vaccinations during the first 24 months of life; among them, the mean days undervaccinated was 232. Relatively few children had short periods of delay (3% for 1-7 days, 6% for 8-31 days, and 12% for 1-2 months) while more children were delayed for longer periods (17% for 3-6 months and 22% for 7-12 months). Approximately 15% of all children were undervaccinated for more than 12 of their first 24 months of life. Among children with any delay, 52% were undervaccinated for more than 6 months.

Individual Vaccines

Children were less likely to be delayed for each individual vaccine than for the series as a whole. The percentage of children with any delay ranged from 54% for the recommended doses of Hib vaccine and 48% for DTaP vaccine to 32% for poliovirus vaccine and less than 30% for hepatitis B, MMR, and varicella vaccines (Table 2). However, considerable numbers of children remained undervaccinated with each vaccine for a substantial portion of their first 24 months of life. Approximately 10% to 20% of children were undervaccinated for more than 6 months for DTaP, hepatitis B, Hib, and poliovirus vaccines. For MMR and varicella vaccines, the total possible delay is considerably shorter. Nevertheless, 11% of children were undervaccinated for 7 or more of the possible 8 months of delay for MMR vaccine and 20% were undervaccinated for 3 or more of the possible 5 months of delay for varicella vaccine.

The number of vaccines for which children had delays is presented in Table 3. Overall, 47% of children had no delayed vaccinations or were delayed for only 1 of the 6 vaccines. Approximately 28% of children had delays for 2 or 3 vaccines, and 25% had delays in receipt of 4 or more of the 6 vaccines.

Severe Delay and Risk Factors

Approximately 21% of children were undervaccinated for more than 6 months and for 4 or more antigens (Table 3) and were considered severely delayed in their early childhood vaccinations. In multivariate analysis, factors associated with severe delay of vaccinations included having a mother who was unmarried or who did not have a college degree, liv-
ing in a household with 2 or more children, being non-Hispanic black, having 2 or more vaccination providers, and using public vaccination providers (Table 4).

**Lenient Catch-up Outcome Measure**

When the required interval between catch-up doses was not counted as days undervaccinated, results changed only slightly. For the complete vaccination series, days undervaccinated declined from a mean of 172 days to 163 days. For individual vaccines, this reduction ranged from 0 to 10 days. The percentage of children undervaccinated for more than 6 months remained approximately the same (36% vs 37%), and the percentage of children severely delayed remained 21%.

**Delay and Vaccination Coverage**

Children who were completely vaccinated at the time of the household interview or at 24 months had fewer days undervaccinated and fewer vaccines delayed than did those who were not completely vaccinated. However, even among the 74% of children who were up-to-date at the time of the interview, 23% were undervaccinated for more than 6 months during the first 24 months of life, with fewer than half undervaccinated for less than 1 month (Figure). In addition, 42% were delayed for multiple vaccines. Similarly, among the 67% of children who were up-to-date at 24 months of age, 18% were undervaccinated for more than 6 months and 37% were delayed for multiple vaccines. Traditionally estimated vaccination coverage decreased with longer period undervaccinated; vaccination coverage at the time of interview was 100% among children undervaccinated for less than 1 month, 82% (SE, 0.9%) among children undervaccinated for 1 to 6 months, and 46% (SE, 1.1%) among children undervaccinated for more than 6 months. Twenty-four month coverage was 100% among children undervaccinated for less than 1 month, 74% (SE, 1.1%) among children undervaccinated for 1 to 6 months, and 32% (SE, 1.0%) among children undervaccinated for more than 6 months.

**COMMENT**

Vaccination coverage rates have reached record-high levels in the United States, with estimated coverage higher than 85% among children aged 19 to 35 months for DTaP and varicella vaccines, higher than 90% for poliovirus, MMR, hepatitis B, and Hib vaccines, and 73% for the combined series of all of these vaccines. These results highlight substantial successes of national, state, and local vaccination programs in increasing the proportion of children who have accumulated the required number of vaccinations by 19 to 35 months of age. However, reliance on this indicator alone masks substantial delays during the first 2 years of life prior to becoming fully vaccinated. Few children receive all vaccinations on time. Moreover, we found that the delays are not trivial: only 1 in 3 children were age-appropriately vaccinated or undervaccinated for less than 1 month cumulatively during the first 24 months of life; 37% of children were undervaccinated for more than 6 months; and more than half of children were delayed with multiple vaccines. Among children with any delay, most were undervaccinated for more than 6 months. Even among children who would be considered up-to-date by traditional coverage estimates, 23% were undervaccinated for more than 6 of the first 24 months of life and 42% were delayed for multiple vaccines. These results confirm that opportunity exists for improvement in vaccine administration in the United States to ensure that all children remain fully vaccinated and optimally protected from vaccine-preventable diseases throughout early childhood—the time when children are most at risk for illness and severe complications from many vaccine-preventable diseases.

Most troubling are children who are undervaccinated for more than 6 months during the first 24 months of life and those who are delayed for 4 or more vaccines, and especially the 21% of children who are severely delayed. These delays signify problems with access to care and vaccine delivery and highlight risk of disease more than do delays of a few days or delays in receipt of a single vaccine. Furthermore, most children who were undervaccinated for more than 6 months did not catch up by the time the caregiver was interviewed for the NIS when the child was aged 24 to 35 months.

Risk of disease due to delay in vaccine administration varies, and depends on the vaccine, disease circulation, transmissibility, likelihood of importation, and severity of outcome. While vaccine-preventable disease incidence is generally low in the United States, vaccination timeliness is particularly important for diseases that have the potential to cause large outbreaks, such as measles, and for diseases that currently are circulating, such as pertussis.
We found that 11% of children were undervaccinated for measles for more than 6 of a possible 8 months during the first 24 months of life and another 3% were undervaccinated for 3 to 6 months. Because only a single dose of measles vaccine is recommended in early childhood, these delays represent a period of complete lack of protection against measles. Elimination efforts have greatly reduced the incidence of measles in the United States to only 56 reported cases in 2003. However, risk of importation remains high due to global measles circulation, high rates of transmission, and the large volume of travelers to and from the United States. With each imported measles case, population immunity is tested and an outbreak or epidemic could result if there are enough susceptible hosts due to delays in vaccination, lack of vaccination, or inadequate immune response to vaccination. The US measles epidemic in 1989 to 1991 was caused by a failure to provide timely vaccination, and according to the Centers for Disease Control and Prevention, "only a sustained effort to provide age-appropriate vaccination will prevent another resurgence of measles."

Pertussis is another example of the importance of timely vaccination. During 2003, 11647 cases of pertussis were reported in the United States, incidence was highest among infants who were younger than 6 months and infants accounted for the highest proportion of pertussis-related hospitalizations and deaths. Among infants who contracted pertussis during the 1990s, at least 44% were undervaccinated for their age. Furthermore, among the 25 pertussis-related deaths in infants aged 2 to 11 months, 15 had not received any doses of pertussis vaccine. While these children were too young to have received the complete 4-dose series of DTaP, data suggest that the risk of pertussis-related hospitalization is decreased if children have received 1 or 2 doses of vaccine. Furthermore, because siblings are a source of transmission to infants too young to be vaccinated, timely vaccination of these children can indirectly protect young infants by decreasing their exposure. We found that 16% of children were undervaccinated for DTaP for more than 6 of the first 24 months of life and another 14% were undervaccinated for 3 to 6 months.

In addition to risk of disease and disease outbreaks, delayed vaccinations

### Table 4. Factors Associated With Severe Delay in Early Childhood Vaccinations*

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Bivariate % (SE)†</th>
<th>P Value</th>
<th>Multivariate Adjusted OR (95% CI)‡†</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>14100</td>
<td>20.5 (0.6)</td>
<td>&lt;.001</td>
<td>1.0</td>
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<tr>
<td>Maternal age, y</td>
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</tr>
<tr>
<td>&lt;20</td>
<td>277</td>
<td>28.7 (4.4)</td>
<td>&lt;.001</td>
<td>1.0</td>
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<tr>
<td>20-30</td>
<td>6023</td>
<td>22.9 (0.9)</td>
<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
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<tr>
<td>&gt;30</td>
<td>8510</td>
<td>17.9 (0.8)</td>
<td>&lt;.001</td>
<td>1.3 (1.1-1.6)</td>
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<td>Maternal marital status</td>
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<td>Married</td>
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<td>Not married</td>
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<td>26.2 (1.2)</td>
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<td>Maternal education</td>
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<tr>
<td>&lt;High school</td>
<td>1966</td>
<td>28.5 (1.6)</td>
<td>&lt;.001</td>
<td>2.3 (1.9-3.0)</td>
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<tr>
<td>&gt;High school</td>
<td>3932</td>
<td>22.3 (1.0)</td>
<td>&lt;.001</td>
<td>1.7 (1.4-2.1)</td>
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<td>College graduate</td>
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<td>Urban vs rural (by metropolitan statistical area [MSA])</td>
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<tr>
<td>MSA central city</td>
<td>6575</td>
<td>21.4 (0.9)</td>
<td>&lt;.001</td>
<td>1.0</td>
</tr>
<tr>
<td>MSA noncentral city</td>
<td>5221</td>
<td>18.9 (0.9)</td>
<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
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<tr>
<td>Non-MSA</td>
<td>3014</td>
<td>22.5 (1.2)</td>
<td>&lt;.001</td>
<td>1.3 (1.1-1.6)</td>
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<td>Census region</td>
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<td>Northeast</td>
<td>2472</td>
<td>19.3 (1.3)</td>
<td>&lt;.001</td>
<td>1.0</td>
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<td>Midwest</td>
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<td>20.7 (1.1)</td>
<td>&lt;.001</td>
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<td>West</td>
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<td>1.3 (1.1-1.6)</td>
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<td>21.5 (1.3)</td>
<td>&lt;.001</td>
<td>1.3 (1.1-1.6)</td>
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<td>Poverty status</td>
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<td>At or below poverty line</td>
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<td>26.6 (1.3)</td>
<td>&lt;.001</td>
<td>1.0</td>
</tr>
<tr>
<td>Above poverty line</td>
<td>10643</td>
<td>17.8 (0.6)</td>
<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
</tr>
<tr>
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<td>1319</td>
<td>22.1 (2.0)</td>
<td>&lt;.001</td>
<td>1.0</td>
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<td>No. of children in household</td>
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</tr>
<tr>
<td>1</td>
<td>3723</td>
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<td>&lt;.001</td>
<td>1.0</td>
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<tr>
<td>≥2</td>
<td>11087</td>
<td>22.6 (0.7)</td>
<td>&lt;.001</td>
<td>1.8 (1.5-2.2)</td>
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<tr>
<td>Child’s race/ethnicity</td>
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<tr>
<td>Non-Hispanic white</td>
<td>8838</td>
<td>18.1 (0.7)</td>
<td>&lt;.001</td>
<td>1.0</td>
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<tr>
<td>Non-Hispanic black</td>
<td>2076</td>
<td>28.2 (1.7)</td>
<td>&lt;.001</td>
<td>1.3 (1.1-1.6)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>3053</td>
<td>20.7 (1.3)</td>
<td>&lt;.001</td>
<td>0.8 (0.7-1.0)§</td>
</tr>
<tr>
<td>Other</td>
<td>843</td>
<td>22.8 (2.6)</td>
<td>&lt;.001</td>
<td>1.3 (0.9-1.8)</td>
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<tr>
<td>Child’s sex</td>
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<tr>
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<td>7690</td>
<td>20.7 (0.8)</td>
<td>&lt;.001</td>
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<tr>
<td>Female</td>
<td>7117</td>
<td>20.2 (0.8)</td>
<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
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<td>No. of vaccination providers</td>
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<td></td>
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</tr>
<tr>
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<td>10173</td>
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<td>&lt;.001</td>
<td>1.0</td>
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<tr>
<td>≥2</td>
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<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
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<tr>
<td>Type of vaccination provider(s)</td>
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<tr>
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<td>&lt;.001</td>
<td>1.0</td>
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<td>&lt;.001</td>
<td>1.6 (1.3-1.9)</td>
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<td>Other/mixed</td>
<td>3578</td>
<td>22.8 (1.2)</td>
<td>&lt;.001</td>
<td>1.2 (1.0-1.4)</td>
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Abbreviations: CI, confidence interval; OR, odds ratio.

*Children undervaccinated for more than 6 months during the first 24 months of life and delayed for 4 or more of 6 vaccines: diphtheria and tetanus toxoids and acellular pertussis; poliovirus; measles, mumps, and rubella; Haemophilus influenzae type b; hepatitis B; and varicella.

†Based on weighted data.

‡Final main-effects model. Variables in column 1 with P < .10 were eliminated through standard backward elimination.

§The 95% CI does not include 1 when carried out to more than 1 decimal place.
have administrative implications. Vaccine providers report difficulty in assessing vaccination status and determining appropriate catch-up regimens for children who have fallen behind in their vaccinations. Also, children who fall behind are less likely to be fully vaccinated at later times. Preventing children from falling behind and immediate identification of delays present opportunities to intervene earlier and to ensure full vaccination.

This study is subject to several limitations. First, the NIS is a telephone survey and relies on identification of vaccination providers by the household respondent and on complete and accurate reporting of vaccination histories by these providers. Bias may have occurred due to households without telephones and household nonresponse. Furthermore, if some vaccination providers were not identified or if some providers did not report complete histories, we may have misclassified children as not having been completely vaccinated. However, the NIS uses a variety of weighting strategies to reduce bias and to ensure that all children in the United States are represented by children with adequate provider data. Also, the NIS lacks additional information that could provide a better understanding of the reasons for undervaccination and how to ensure that children receive vaccinations as recommended, such as parental reasons for delay. Information on all health care visits would enable an assessment of the proportion of delay attributable to missed opportunities for vaccination. Finally, vaccine shortages in the United States during 2000 to 2002 may have affected timeliness of MMR, DTaP, and varicella vaccinations for children in this analysis. However, the effect of the shortages on receipt of vaccines has been shown to be small.

Previously, we found that 18% of children in the 2000 NIS received all vaccines as recommended or acceptable early. In the current study, we found that 26% did not have any days undervaccinated. However, these results are not directly comparable due to slight differences in case definitions. Most notably, in the previous study we considered a child to be delayed if they were late by any amount, while in the current study we considered a child to be delayed only after they were late for at least 1 full day (for example, at 93 days rather than 92 days for doses due at age 2 months). When the slightly more stringent definition is applied to the current study, 9% of children shift from the 0 days undervaccinated category to the 1 to 7 days undervaccinated category, leaving 17% of children without any days undervaccinated, comparable with previous findings. Results for more severe levels of delay are not affected.

Results of this study have important implications for clinical practice and public policy. The major concern for underimmunized children is disease occurrence, especially in the 21% of children who were severely delayed. Factors leading to underimmunization that need to be addressed include reducing racial and ethnic disparities, and assisting women who are unmarried, have less than a high school education, have multiple children, have multiple vaccine providers, and use public vaccination clinics. Interventions must be focused on plans that could best address the needs of these mothers, such as extended office hours for women who have difficulty taking time away from work, using appropriate education-level information regarding safety and benefits of vaccination, and ensuring availability of sibling child care in the workplace.

In addition, systems need to be implemented to identify children who are behind on immunizations, which will help in 2 areas. The first is to enable the recall of children soon after they fall behind on their immunizations, and the second is to ensure that opportunities to immunize children when they are seen for other medical reasons are not missed. Conversely, immunization visits provide an opportunity for delivery of other much needed preventive services recommended by the American Academy of Pediatrics. Immunization coverage has been shown to be a marker for delivery of other important preventive health care services in children.

Assessing days undervaccinated reveals weaknesses in childhood vaccination programs. Physicians are in the best

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**Figure.** Months Undervaccinated and Number of Vaccines Delayed Among Children Traditionally Considered Up-to-Date

- **Children**
  - **Up-to-Date at Interview**
  - **Up-to-Date at 24 mo**

- **Vaccines**
  - **No. of Vaccines Delayed**

Months undervaccinated is based on cumulative days undervaccinated during the first 24 months of life for 1 or more doses of a recommended vaccine. Delay begins after the end of a recommendation period and continues until the child is vaccinated or reaches 24 months of age. Vaccines delayed out of 6 vaccines: diphtheria and tetanus toxoids and acellular pertussis; poliovirus; measles, mumps, and rubella; Haemophilus influenzae type b; hepatitis B; and varicella. A child is up-to-date if he/she received 4 or more doses of diphtheria and tetanus toxoids and acellular pertussis vaccine; 3 or more doses of poliovirus vaccine; 1 or more doses of measles, mumps, and rubella vaccine; 3 or more doses of hepatitis B vaccine; and 1 or more doses of varicella vaccine. Percentage of children based on weighted data. Asterisk indicates that data are from the 74% (SE, 0.6%) of children who were up-to-date at the time of the household interview (age, 24-35 months). Dagger indicates that data are from the 67% (SE, 0.2%) of children who were up-to-date at age 24 months.
position to assess the needs of their patients to determine reasons for delay. Evi-
dence-based solutions exist for many of these needs, such as reminder-recall sys-
tems, extended office hours, expanding availability of pediatric care, and educa-
tion regarding the importance and safety of vaccinations. 46-47 Minimizing the time spent incompletely protected from vac-
cine-preventable diseases is important to the health of individuals and to public health and should be given greater em-
phasis by public health programs and vaccination providers.

**Author Contributions:** Dr Luman had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Study concept and design:** Luman, Ruehler, Pickering, and Buehler. Analysis and interpretation of data: Luman, Barker, Shaw, McCauley.

**Drafting of the manuscript:** Luman, Shaw. Critical revision of the manuscript for important int-
elleltual content: Luman, Barker, McCauley, Ruehler, Pickering.

**Statistical analysis:** Luman, Barker, Shaw.

**Study supervision:** Barker.

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**Role of the Sponsor:** This study, including design and conduct, data collection, analysis and interpretation of the data, and manuscript preparation, review, and approval was conducted under the auspices of the De-
partment of Health and Human Services and the Cen-
ters for Disease Control and Prevention. The Centers for Disease Control and Prevention gave final ap-
proval of the manuscript.

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