Risk Factors for Delay in Age-Appropriate Vaccination

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SYNOPSIS

Objective. To estimate the risk factors of children experiencing delay in age-appropriate vaccination using a nationally representative population of children, and to compare risk factors for vaccination delay with those based on up-to-date vaccination status models.

Methods. The authors compared predictors of delay in age-appropriate vaccination with those for children who were not up-to-date, using a nationally representative sample of children from five years of pooled data (1992–1996) from the National Health Interview Survey (NHIS) Immunization Supplement. Duration of delay was calculated for the DTP4, Polio3, MMR1 doses and 4:3:1 series using age-appropriate vaccination standards; up-to-date status (i.e., whether or not a dose was received) was also determined. Adjusted odds ratios were estimated using multivariate logistic regression for models of vaccination delay and up-to-date vaccination status.

Results. Absence of a two-parent household, large family size, parental education, Medicaid enrollment, absence of a usual provider, no insurance coverage, and households without a telephone were significantly related to increased odds of a child experiencing vaccination delay ($p \leq 0.05$).

Conclusions. Many of the risk factors observed in models of vaccination delay were not found to be significant in risk models based upon up-to-date status. Consequently, risk models of delays in age-appropriate vaccination may foster identification of children at increased risk for inadequate vaccination. Populations at increased risk of inadequate vaccination can be more clearly identified through risk models of delays in age-appropriate vaccination.

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The underimmunization of preschool children has been a persistent public health problem throughout the United States during the past decade. Although immunizations are considered to be the most cost-effective clinical preventive service for children,[1] many children experience lengthy delays prior to receiving recommended vaccinations.[2,3] As a consequence, the *Healthy People 2010* objective of having 80% of the nation's children 2 years of age and younger fully immunized remains an elusive goal. Recent data from the Centers for Disease Control and Prevention (CDC) indicate that only 79% of children 19–35 months of age have received their fourth diphtheria-tetanus-pertussis vaccine (DTP4), third poliovirus vaccine (Polio3), first measles-mumps-rubella (MMR1), third *Haemophilus influenzae* type b (Hib), and third hepatitis B vaccine doses (i.e., the 4:3:1:3:3 vaccination series).[4] Elevated risk of vaccination delay can potentially have severe consequences. For example, lengthy delays in Hib vaccination during a child's first 18 months would increase the likelihood of invasive Hib disease, since this is the age of a child's peak susceptibility.[5,6]

Previous research suggests that vaccination status is influenced by factors such as the child's health status, economic status, parental health attitudes, and family characteristics.[7–11] The effects of these risk factors may be mediated by demographic factors including the child's age, poverty status, geographic location, race, ethnicity, and the education level of parents.[12–15] However, the generalizability of the results from most of these studies is constrained by the limited or relatively small populations upon which the studies were based. Other studies have employed data from populations which are broader in scope, such as statewide cohorts of school-entering children or national health plans.[16–18] Although some of these larger studies have improved generalizability, the risk factor analysis has often been limited to basic demographic information.

The majority of studies that have assessed the risks associated with inadequate immunization status have employed up-to-date status (i.e., whether or not doses were ever received) as the outcome measure.[19] Few studies have considered the risk factors for vaccination delays from the perspective of whether the doses were administered at or near the recommended age, and none of these studies have been conducted on nationally representative samples.[11,12,20] Moreover, no studies conducted to date have considered that the risks of relatively short vaccination delays may differ from the risks of relatively long delays.

We undertook this study to extend what is known about the risks of vaccination delay in three important ways. First, we consider the risk of vaccination delay from a new perspective: we use a model that is sensitive to the possibility that the risk of vaccination delay may vary as the duration of vaccination delay increases (i.e., the risks associated with relatively short delays may differ from those for long delays). In addition to determining the risks of delayed vaccination, the statistical methods employed in this study permit an assessment of whether the risk factors associated with lengthy vaccination delays differ from the risk factors for shorter delays. Second, we contrast those findings with results from similar models that estimate vaccination status based on up-to-date criteria. Third, we base our analysis upon a nationally representative sample of children, extending the generalizability of previous research conducted on smaller population samples.

METHODS

We obtained data from the National Health Interview Survey (NHIS) Immunization Supplement public use files for the years 1992 through 1996, which were the most current national immunization data available at the time this study was conducted.[21] The NHIS is a cross-sectional survey conducted annually that is representative of the civilian, non-institutionalized population of the United States. For the years prior to 1994, the NHIS Immunization Supplement provides detailed vaccination information for one randomly-selected child younger than 6 years of age within each sampled household; from 1994 onward, all children ages 19–35 months in sampled households are included. Specific dates of vaccination administration are collected and the precise date of vaccination for a dose is recorded only for responses that are based upon written records. The basic content of the Immunization Supplement survey was constant for the period 1992–1996, providing detailed information on household economic indicators and demographic characteristics of the respondent (i.e., the proxy respondent for the sample children).[22] For each demographic characteristic, Pearson chi-square tests of association were conducted comparing the subset of children having written vaccination records with those having vaccination histories based upon parental recall.

A retrospective assessment of vaccination up-to-date status and duration of any delay based upon the 1996 immunization schedule for the DTP4, Polio3, and MMR1 doses was conducted for all children 25–72 months of age.[23] Although the recommended vaccination schedule underwent modifications during the years considered in this study, the maximum recommended age for completion of the DTP4, Polio3, and the 4:3:1 vaccination series was 18 months of age, and the maximum recommended age for completion of the MMR1 dose was 15 months of age. The age at vaccination (in months) was determined for each vaccine dose; DTP4 and Polio3 doses received at 19 months of age or later were considered to be delayed (by one month) and MMR1 doses received at 16 months of age or later were likewise considered delayed. The outcome measure of delay in months was categorized to facilitate interpretation of results, with each dose being coded as either having no delay, a delay of one to six months, seven months or longer delay, or that the respective vaccine dose was not recorded. Similarly, up-to-date status was also determined for each dose and the overall 4:3:1 series. All subjects included in this study were at least 25 months of age and therefore old enough to potentially experience vaccination delays of seven months or longer (i.e., younger children were excluded from the analysis since they would have no likelihood of experiencing delays of this duration).

Two sets of multivariate logistic regression models were estimated using the MULTILOG procedure in SUDAAN.[24] First, a dichotomous model of up-to-date vaccination status was estimated for each of the three vaccine doses and the 4:3:1 series. A parallel set of models was estimated using the same independent variables and a multinomial outcome variable indicating the four categories of vaccination delay noted above. NHIS Immunization Supplement sampling weights and the corresponding sampling strata identifiers were used in all computations of standard errors and confidence intervals using Statistical Analysis System (SAS) version 6.12 in conjunction with SAS-callable SUDAAN version 7.5.[24,25]

RESULTS

A total of 23,487 responses for children 25–72 months of age were obtained from the NHIS Immunization Supplements for the 1992–1996 study period. The demographic characteristics of NHIS responses for children 25–72 months of age are shown in Table 1, contrasting the 9,223 responses based upon written vaccination information (39%) with the 14,264 children who had responses based only upon parental recall of vaccination history (61%). These two subsets were found to differ significantly by race, ethnicity, geographic location of household, and poverty status (α=0.05). Despite these differences, the remainder of analyses were based only upon children with written immunization records, since the NHIS collects date-of-vaccination for only those children.

Models of up-to-date status

A substantial majority (80%, 95% confidence interval [CI] 79.1, 81.1) of children 25–72 months of age were found to have completed the 4:3:1 series. Similarly, 84% (95% CI 82.9, 84.8) of children were up-to-date for DTP4, 90% (95% CI 89.4, 90.8), for Polio3, and 96% (95% CI 95.6, 96.6) for MMR1. Table 2 summarizes the results from logistic regression models estimating the odds of a child not being up-to-date for either the DTP4, Polio3, or MMR1 doses or the overall 4:3:1 series. The table shows that, when controlling for gender, race, ethnicity, and urbanicity differences (results not shown), only two additional characteristics were significantly related to the odds of not being up-to-date. The number of children in a family was found to be associated with increased odds of not being up-to-date for the Polio3 dose; children from two-child families had 15% higher odds (odds ratio [OR]=1.15; 95% CI 1.05, 1.26) of not being up-to-date for the Polio3 dose, compared to children without siblings. For children from families with four or more children, the odds of Polio3 dose not being up-to-date are over one and half times that of a without siblings (OR=1.52; 95% CI 1.38, 1.68). In addition, not having a usual provider was associated with increased odds of the MMR1 dose (OR=1.67; 95% CI 1.08, 2.59) and the 4:3:1 series (OR=1.39; 95% CI 1.02, 1.89) not being up-to-date. None of the factors in Table 2 were found to have significant associations with the odds of not being up-to-date for the DTP4 dose.

Models of vaccination delay

Many children ages 25–72 months were found to have experienced delay prior to completing the 4:3:1 series. Although 84% of children were up-to-date for DTP4, only 46% (95% CI 44.8, 47.4) received the dose without delay; 64% (95% CI 62.7, 65.1) had no Polio3 delay and 57% (95% CI 56.1, 58.7) had no delay prior to receiving the MMR1 dose. Overall, only 33% (95% CI 31.3, 33.8) completed the 4:3:1 series without delay.

Multinomial models of vaccination delay were estimated using the same independent variables included in our models of up-to-date vaccination status. The model results for the DTP4, Polio3, MMR1, and 4:3:1 series results are summarized in Table 3 and are adjusted for gender, race, ethnicity, and urbanicity. Family characteristics were found to be significantly associated with vaccination delay for each of the three doses and the overall series. Households having two parents were consistently associated with reduced risk of vaccination delay for each dose modeled. Children from two-parent households had lower odds of six-month

Table 1. NHIS immunization respondents, 25–72 months of age, 1992–1996

Characteristic	*NHIS responses with written vaccination history (percent) n=9,223*	*NHIS responses with no written vaccination history (percent) n=14,264*
Age		
25–35 months	24.0	23.2
36–47 months	12.3	13.6
48–59 months	26.0	25.6
60–71 months	26.4	25.8
72 months	11.4	11.8
Gender		
Male	51.7	50.7
Female	48.3	49.3
Race		
White	83.5	76.6
African American	12.0	18.9
Other	4.5	4.5
Ethnicity		
Hispanic	18.3	13.0
Non-Hispanic	81.4	86.8
Unknown	0.3	0.2
Geographic location		
Urban	30.5	31.9
Suburban	47.6	48.8
Rural	21.9	19.3
Income		
At or above poverty threshold	73.6	71.7
Below poverty threshold	21.7	19.8
Unknown	4.7	8.5

NHIS = National Health Interview Survey

or shorter delays (OR= 0.75; 95% CI 0.60, 0.95) as well as considerably lower odds of delays lasting seven months or longer (OR=0.63; 95% CI 0.48, 0.82) for the 4:3:1 series. In addition, children from two-parent homes also had substantially lower odds of not completing the 4:3:1 series (OR= 0.74; 95% CI 0.59, 0.94). Table 3 illustrates similar findings for the DTP4, Polio3, and MMR1 doses.

Table 3 illustrates that the odds of vaccination delay for each dose and the overall series increased substantially with increased family size. For example, children from families with two children had nearly one and a half times the odds of a seven month or longer DTP4 delay (OR=1.47; 95% CI 1.34, 1.61), compared to their counterparts without siblings; the odds of such delays were over three times as likely (OR=3.13, 95% CI 2.83, 3.45) for children from families with four or more children, compared to children without siblings.

In contrast to the dichotomous models of vaccination status, the multivariate models of vaccination delay also illustrate several indicators of socioeconomic status that are significantly associated with the odds of inadequate vaccination. Table 3 shows that children from households with parents having education beyond a high school diploma had significantly lower odds of vaccination delay. The table illustrates that these children had consistently lower odds of delay for the individual DTP4, Polio3, and MMR1 doses as well as for the overall 4:3:1 series.

Several indicators of poor economic status were found to be associated with increased odds of vaccination delay. Children with Medicaid coverage were found to have increased odds of lengthy delays (i.e., ≥seven months) for the Polio3 and MMR1 doses; 7% of households were without a telephone and were significantly more likely to experience seven month or longer vac-

Table 2. Logistic regression odds ratios for DTP4, Polio3, and MMR1 not up-to-date[a]

	DTP4 Not up-to-date		*Polio3 Not up-to-date*		*MMR1 Not up-to-date*		*4:3:1 series Not up-to-date*	
Characteristic	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Family Unit								
All others families	1.00		1.00		1.00		1.00	
Two parents	0.93	0.74, 1.15	0.85	0.64, 1.14	1.11	0.77, 1.45	0.94	0.77, 1.14
Number of children								
One	1.00		1.00		1.00		1.00	
Two	1.08	0.99, 1.18	1.15	1.05, 1.26	1.03	0.88, 1.20	1.07	0.99, 1.15
Three	1.17	1.09, 1.27	1.32	1.20, 1.46	1.06	0.91, 1.24	1.15	1.06, 1.24
Four or more	1.27	1.18, 1.37	1.52	1.38, 1.68	1.09	0.94, 1.28	1.23	1.14, 1.33
Education level								
High school or less	1.00		1.00		1.00		1.00	
>High school	0.92	0.77, 1.10	0.82	0.64, 1.04	0.73	0.52, 1.03	0.85	0.72, 1.01
Poverty level								
Above	1.00		1.00		1.00		1.00	
Below	1.12	0.88, 1.42	1.04	0.78, 1.38	1.14	0.70, 1.78	1.06	0.85, 1.33
Telephone								
Owns	1.00		1.00		1.00		1.00	
Does not own	1.30	0.95, 1.78	0.98	0.69, 1.39	1.29	0.78, 2.14	1.25	0.93, 1.69
Insurance								
No insurance	1.00		1.00		1.00		1.00	
At least some	0.84	0.65, 1.09	0.87	0.62, 1.21	0.78	0.51, 1.20	0.87	0.69, 1.09
Medicaid status								
Not covered	1.00		1.00		1.00		1.00	
Covered	1.02	0.80, 1.31	0.94	0.68, 1.30	0.93	0.58, 1.50	0.99	0.79, 1.24
Usual source of medical care								
Usual provider	1.00		1.00		1.00		1.00	
No usual provider	1.40	0.98, 2.00	1.31	0.85, 2.00	1.67	1.08, 2.59	1.39	1.02, 1.89

[a]Odds ratios are adjusted for gender, race, ethnicity, and urbanicity.

DTP4 = fourth dose of diphtheria and tetanus toxoids and pertussis vaccine.

Polio3 = third dose of poliovirus vaccine.

MMR1 = first dose of measles, mumps, rubella vaccine.

4:3:1 series = four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine.

cination delays for each dose, and for the 4:3:1 series. When each of these factors is taken into account, poverty status was not significantly related to vaccination delay with the exception of the Polio3 dose, where poverty status was associated with lower odds of seven month or longer delay.

Whether or not children had some form of medical insurance significantly influenced the odds of vaccination delay consistently for each dose and the overall series. Children having at least some medical insurance were half as likely to have a lengthy (i.e., seven months or longer) vaccination delay, compared to their counterparts without any medical insurance. In addition, children with at least some medical insurance were less likely to experience shorter delays (one–six months) for the MMR1, and less likely to have an incomplete 4:3:1 series. Children without a usual source of medical care were much more likely to have a lengthy 4:3:1 series delay (i.e., ≥seven months) compared to their counterparts with a usual provider. In addition, children without a usual provider were over one and a half times as likely to not receive the DTP4 and MMR1 doses and have an incomplete 4:3:1 series.

In summary, these results illustrate numerous characteristics that are significantly associated with vaccination delay, many of which are distinct from those found in our models of up-to-date status. Table 4 summarizes the factors we observed to have statistically significant associations in the models of vaccination delay (Table 3) and contrasts them with those from our up-to-date status models (Table 2).

Table 3. Multinomial logistic regression odds ratios for delay in age-appropriate vaccination[a]

	DTP4 delay					
	1–6 months delay		*7 or more months delay*		*No vaccination recorded*	
Characteristic	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Family unit						
All other families	1.00		1.00		1.00	
Two parents	0.74	0.59, 0.92	0.64	0.50, 0.82	0.77	0.60, 0.98
Number of children						
One	1.00		1.00		1.00	
Two	1.15	1.06, 1.25	1.47	1.34, 1.61	1.22	1.11, 1.34
Three	1.32	1.22, 1.43	2.14	1.94, 2.36	1.49	1.35, 1.65
Four or more	1.52	1.41, 1.65	3.13	2.83, 3.45	1.82	1.65, 2.01
Education level						
High school, or less	1.00		1.00		1.00	
> High school	1.03	0.86, 1.23	0.76	0.61, 0.94	0.88	0.73, 1.07
Poverty level						
Above	1.00		1.00		1.00	
Below	1.02	0.79, 1.32	1.07	0.81, 1.41	1.15	0.89, 1.49
Telephone						
Owns	1.00		1.00		1.00	
Does not own	0.97	0.68, 1.39	1.73	1.20, 2.50	1.55	1.06, 2.26
Insurance						
No insurance	1.00		1.00		1.00	
At least some	1.03	0.79, 1.35	0.50	0.38, 0.66	0.72	0.55, 0.95
Medicaid status						
Not covered	1.00		1.00		1.00	
Covered	1.06	0.86, 1.31	1.24	0.97, 1.59	1.07	0.82, 1.39
Usual source of medical care						
Usual provider	1.00		1.00		1.00	
No usual provider	1.06	0.70, 1.60	1.43	0.98, 2.08	1.56	1.06, 2.29

continued on p. 150

Table 3 (continued). Multinomial logistic regression odds ratios for delay in age-appropriate vaccination[a]

	Polio3 Delay					
	1–6 months delay		*7 or more months delay*		*No vaccination recorded*	
Characteristic	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Family unit						
All other families	1.00		1.00		1.00	
Two parents	0.80	0.61, 1.04	0.54	0.41, 0.71	0.74	0.56, 0.95
Number of children						
One	1.00		1.00		1.00	
Two	1.20	1.10, 1.31	1.46	1.31, 1.63	1.25	1.13, 1.37
Three	1.43	1.30, 1.58	2.14	1.90, 2.41	1.55	1.41, 1.71
Four or more	1.72	1.56, 1.89	3.13	2.78, 3.52	1.93	1.75, 2.13
Education level						
High school, or less	1.00		1.00		1.00	
> High school	0.99	0.82, 1.20	0.67	0.51, 0.88	0.78	0.61, 0.99
Poverty level						
Above	1.00		1.00		1.00	
Below	0.80	0.60,1.07	0.70	0.54, 0.91	0.94	0.70, 1.27
Telephone						
Owns	1.00		1.00		1.00	
Does not own	0.89	0.60, 1.32	1.86	1.32, 2.64	1.10	0.76, 1.61
Insurance						
No insurance	1.00		1.00		1.00	
At least some	1.20	0.91, 1.58	0.56	0.40, 0.79	0.82	0.59, 1.15
Medicaid status						
Not covered	1.00		1.00		1.00	
Covered	1.05	0.82, 1.35	1.36	1.01, 1.84	0.99	0.71, 1.37
Usual source of medical care						
Usual provider	1.00		1.00		1.00	
No usual provider	1.23	0.81, 1.86	1.14	0.75, 1.73	1.36	0.89, 2.09

continued on p. 151

DISCUSSION

The findings of this study illustrate the important distinction between assessing the risks of delays in age-appropriate vaccination versus the risks of a child not being up-to-date. These results are consistent with those of other studies,[7–10,13,14,26] but provide additional insight in two important ways. Our findings offer new perspectives on the risk factors of delays in age-appropriate vaccination, since the preponderance of previous research findings are based upon up-to-date status.[19] In addition, our results are nationally representative and broaden previous findings from studies of more localized populations.

These results are especially important to public health officials since risk assessments for inadequate vaccination based upon up-to-date status may suggest limited risk for some population subgroups, yet risks based upon age-appropriate status may reveal substantial inequalities within a population. Knowing these risk factors is essential to the initiation of efforts focused on improving vaccination rates, as well as other primary care services. There is evidence to suggest that outreach to children who are delayed for recommended vaccinations is likely to reach subpopulations that are also in need of lead, tuberculosis, or other screening services.[27]

The multinomial outcome variables modeled in this study offer a more precise metric that can better reveal the risk factors associated with inadequate vaccination. In addition, the results of this study demonstrate that multinomial models of delay can characterize children in all possible states of vaccination status, ranging from no delay to never having received the vaccination (i.e., not up-to-date). The results of these

Table 3 (continued). Multinomial logistic regression odds ratios for delay in age-appropriate vaccination[a]

	MMR1 Delay					
	1–6 months delay		*7 or more months delay*		*No vaccination recorded*	
Characteristic	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Family unit						
All other families	1.00		1.00		1.00	
Two parents	0.83	0.68, 1.02	0.66	0.49, 0.88	0.97	0.68, 1.40
Number of children						
One	1.00		1.00		1.00	
Two	1.25	1.15, 1.36	1.37	1.23, 1.53	1.14	0.98, 1.34
Three	1.55	1.38, 1.68	1.90	1.69, 2.13	1.32	1.13, 1.52
Four or more	1.93	1.79, 2.09	2.69	2.32, 2.94	1.52	1.30, 1.78
Education level						
High school, or less						
> High school	0.93	0.80, 1.07	0.61	0.49, 0.76	0.68	0.48, 0.96
Poverty level						
Above	1.00		1.00		1.00	
Below	1.18	0.97, 1.43	1.02	0.76, 1.36	1.21	0.73, 1.99
Telephone						
Owns	1.00		1.00		1.00	
Does not own	1.17	0.85, 1.62	1.46	1.00, 2.14	1.48	0.88, 2.49
Insurance						
No insurance	1.00		1.00		1.00	
At least some	0.75	0.59, 0.94	0.49	0.35, 0.69	0.65	0.42, 1.01
Medicaid status						
Not covered	1.00		1.00		1.00	
Covered	0.96	0.78, 1.19	1.53	1.15, 2.05	0.97	0.61, 1.56
Usual source of medical care						
Usual provider	1.00		1.00		1.00	
No usual provider	0.97	0.69, 1.36	1.01	0.62, 1.65	1.64	1.05, 2.58

continued on p. 152

models have intuitive appeal since probabilities of delay from individual categories (e.g., no delay, ≤six months delay, seven or more months delay) can be combined to derive estimates of total up-to-date coverage. These findings demonstrate that substantial differences exist in the factors associated with up-to-date versus age-appropriate vaccination status. These distinctions can lead to a greater understanding of the populations most at risk for inadequate vaccination.

National data suggest that, despite the fact that most children eventually become up-to-date, the problem of delays in age-appropriate vaccination persists.[2] Other findings based on the National Immunization Survey (NIS) indicate that only 22% of children had received each dose of the 4:3:1 series at the recommended ages.[3] Relatively high rates of vaccination delay have been reported elsewhere; only 70% of insured children were up-to-date for the 4:3:1 vaccination series by six years of age.[15] Other evidence suggests that lengthy delays are experienced by many children, who eventually become fully vaccinated as a result of school vaccination laws.[28]

Given the high prevalence of vaccination delay during preschool years, the results of this study are particularly important in order to better understand the subpopulations of children most likely to postpone vaccinations until school entry. Knowing the characteristics of children who are most likely to experience lengthy delays such as these is especially important to reducing the prevalence of inadequately vaccinated children. Our findings suggest that, controlling for race, ethnicity, and other demographic factors, the risks of vaccination delay are strongly influenced by the availability of medical insurance and having a usual

Table 3 (continued). Multinomial logistic regression odds ratios for delay in age-appropriate vaccination[a]

	4:3:1 Series Delay					
	1–6 months delay		7 or more months delay		No vaccination recorded	
Characteristic	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Family unit						
All other families	1.00		1.00		1.00	
Two parents	0.75	0.60, 0.95	0.63	0.48, 0.82	0.74	0.59, 0.94
Number of children						
One	1.00		1.00		1.00	
Two	1.20	1.10, 1.31	1.43	1.29, 1.58	1.25	1.14, 1.37
Three	1.43	1.30, 1.58	2.05	1.86, 2.27	1.55	1.41, 1.71
Four or more	1.72	1.56, 1.89	2.94	2.67, 3.25	1.93	1.75, 2.13
Education level						
High school, or less						
> High school	0.96	0.82, 1.13	0.70	0.57, 0.87	0.77	0.64, 0.93
Poverty level						
Above	1.00		1.00		1.00	
Below	1.06	0.83, 1.36	1.11	0.83, 1.49	1.13	0.86, 1.48
Telephone						
Owns	1.00		1.00		1.00	
Does not own	0.88	0.59, 1.30	1.54	1.01, 2.35	1.41	0.94, 2.13
Insurance						
No insurance	1.00		1.00		1.00	
At least some	0.84	0.65, 1.08	0.50	0.37, 0.67	0.68	0.52, 0.89
Medicaid status						
Not covered	1.00		1.00		1.00	
Covered	0.96	0.78, 1.19	1.19	0.92, 1.54	1.00	0.78, 1.30
Usual source of medical care						
Usual provider	1.00		1.00		1.00	
No usual provider	1.30	0.86, 1.97	1.84	1.22, 2.80	1.83	1.21, 2.79

[a]Odds ratios are adjusted for gender, race, ethnicity, and urbanicity.

DTP4 = fourth dose of diphtheria and tetanus toxoids and pertussis vaccine.

Polio3 = third dose of poliovirus vaccine.

MMR1 = first dose of measles, mumps, rubella vaccine.

4:3:1 series = four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine.

provider. Efforts to improve vaccination rates for these children may be in the form of eligibility criteria, which avoids discontinuity of services under public assistance program such as Medicaid or States Children's Health Insurance Program (SCHIP). Similarly, reduced prevalence of vaccination delay may be influenced by Medicaid policies which encourage increased availability of primary care services for some high-risk children, such as through improvements to reimbursement rates for well-child visits and other mechanisms to foster increased provider participation.

The strong association between family size and vaccination delay observed in this study is consistent with previous findings.[7–11,13,14,26] Decreased parental worry and increased need for family organization have been suggested as possible mechanisms that would adversely influence the immunization status of second-born children.[11] Programs that increase vigilance of age-appropriate vaccination for parents with more than one child may be beneficial. Reducing the risks associated with organizational challenges that confront single parents and those with multiple children may be influenced through public assistance programs that are tied to family size, such as through the Women, In-

Table 4. Summary of statistically significant characteristics[a]

	Up-to-date status models			*Delay status models*		
Characteristic	*DTP4*	*Polio3*	*MMR1*	*DTP4*	*Polio3*	*MMR1*
Gender	X			X		
Race			X	X	X	X
Ethnicity		X			X	X
Urban residence	X	X		X	X	X
Suburban residence						X
Family unit				X	X	X
Number of children in family		X		X	X	X
Income below poverty limit					X	
Education level				X	X	X
Insurance coverage				X	X	X
Medicaid status					X	X
Usual source of medical care			X	X		X
Telephone ownership				X	X	X

[a] DTP4 = fourth dose of diphtheria and tetanus toxoids and pertussis vaccine.

Polio3 = third dose of poliovirus vaccine.

MMR1 = first dose of measles, mumps, rubella vaccine.

4:3:1 series = four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine.

fants, and Children (WIC) program or Temporary Aid to Needy Families (TANF).[29]

Our findings indicate that households without telephones are strongly associated with vaccination delay. The relationship between telephone ownership and vaccination status has been previously documented in conjunction with the development of the NIS,[30–32] suggesting that special consideration be taken to recognize that conventional outreach mechanisms may not be effective for these households. Patient reminder/recall interventions are generally considered to be quite effective in improving vaccination rates, and the most effective outreach mechanisms are thought to be those which are telephone-based.[29,33] The results of this study suggest that caution be exercised when telephone outreach is the sole mechanism for reminder/recall. A surprisingly high proportion of households were found to be without telephones (7%), and those children are arguably among those with the highest likelihood of vaccination delay. Consequently, telephone outreach should be augmented by other mechanisms (e.g., mailed letters or postcards) shown to be effective in increasing vaccination rates.[29,33]

Limitations and future research

Prior studies have shown that parental records can be incomplete and can have a substantial impact on assessment of vaccination status.[34] The results presented here are based solely upon NHIS responses with written vaccination documentation. Since the National Immunization Provider Record Check Study (NIPRCS) data were not available in public use files at the time of this study, we could not perform adjustments to account for incompleteness of parental records. Children without written vaccination records were excluded from this analysis and, given the demographic differences between children with and without written vaccination records, there are likely to be some differences in vaccination delay between these groups. In the NHIS data set used in this study, children with written vaccination records tend to be white race, Hispanic ethnicity, live in rural areas, live in two-parent families, are typically from families not living in poverty, and are covered by insurance. These factors are each associated with *reduced* risk of vaccination delay, and therefore the bias associated with excluding the subpopulation of children who do not have written vaccination records is likely to result in an understatement of the reported risk factors for vaccination delay.[7–11,14,26,35] Although more current NHIS data have been released subsequent to the completion of our study, we believe that our conclusions regarding the improved sensitivity of risk models based upon delays in age-appropriate vaccination would be unlikely to change using more recent data. However, recently released public use data sets now offer the opportunity to consider variations in the risk of vaccination delays from additional perspectives, such as by state and for additional vaccination doses and series, using provider-validated data.

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