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Assessment of Average Days Undervaccinated for U.S. Children Using the National Immunization Survey

By

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Degree to be awarded: Master of Public Health

Department of Epidemiology

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2016

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A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

Assessment of Average Days Undervaccinated for U.S. Children Using the National Immunization Survey

By: Grace G. Kalmus

Background: In the United States, childhood vaccination coverage is relatively high. However, increasing vaccine hesitancy and continued issues of access have led to increased delays in vaccination. While numerous metrics have been used to assess vaccination coverage, average days undervaccinated (ADU), a measure that accounts for every day of life a child is delayed, has not been assessed on a national level.

Methods: Weighted data from the 2017 National Immunization Survey – Child were used to assess vaccination delay among U.S. children ages 19 – 35 months. Vaccination delay was measured using the ADU metric, created by accounting for the time between when a child should have been vaccinated and when the child actually received the vaccination for every recommended dose. Linear and Poisson regression were used to assess the relationship between ADU, the number of vaccination providers a child saw, and other covariates of interest.

Results: In total, 68.2% of the children in the study population were undervaccinated for at least one day of life. Of these children with at least one day undervaccinated, the mean ADU was 94.3 days. ADU was higher for children with three or more vaccination providers than those with two, and was lowest for children with only one provider. Children who lived below the poverty level, were not the firstborn child, had a mother who was less than 30, and did not have private insurance were associated with an increased prevalence of having vaccine delay.

Conclusion: ADU is a measure of vaccine coverage that is more sensitive to vaccine delay than other measures commonly used. Factors associated with higher ADU can provide areas for public health intervention to decrease vaccine delay nationwide.

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Literature Review

Vaccination Trends in the United States

In the United States (U.S.), immunization recommendations for children and adults are made by the Advisory Committee on Immunization Practices (ACIP) (1). As part of these recommendations, the ACIP disseminates an immunization schedule that dictates at what age children should receive each immunization dose. The immunization schedule is designed to provide the maximum possible protection for children from infectious diseases as early in life as the immunization is safe and effective. ACIP recommended vaccines are only those which are FDA-approved and have undergone rigorous safety and efficacy testing. Aside from safety information, ACIP also reviews the severity of the disease for which the vaccination is being recommended, the benefits of vaccination, and the efficacy of vaccination when given at different ages. The ACIP will weigh all of these considerations and publish recommendations which ultimately get adopted by the Centers for Disease Control and Prevention and other organizations, such as the American Academy of Pediatrics and the American Academy of Family Physicians. New information is reviewed regularly to determine whether any updates to the immunization schedule are necessitated (2).

Despite this, alternative vaccination schedules have been increasing in popularity among parents in the U.S. These schedules are non-ACIP schedules that typically either delay immunizations, selectively immunize against some diseases but not others, or limit the number of injections that a child receives in a visit. Nationally, greater than 10 percent of parents report following some type of alternative vaccination schedule (3). Estimates using National Immunization Survey data found that just under a quarter of children followed an alternate vaccination schedule, with an additional 14% having an unknown vaccination pattern (4). Rates of adherence to recommended schedules have been found to vary in certain subpopulations. For instance, a study of children in New York state found that a quarter of the population was following an alternate schedule (5). More concerning, estimates using national immunization data have found that only 9% of children nationally received all immunizations on time according to the ACIP schedule (6). Furthermore, evidence suggests that the number of parents choosing alterative schedules for their children has been increasing in recent years. A study looking at undervaccination, defined as a child having received any doses late or not at all, found that the prevalence of undervaccination significantly increased between 2004 and 2008 (7). Between 2006 to 2009, a study in Portland, OR found that shot-limiting, or not receiving more than 2 vaccine injections per provider visit, increased from 2.5% to 10% of the study population (8). School immunization exemptions, particularly religious exemptions and personal belief exemptions, have also been significantly increasing over time (9),(10).

Consequences of Not Vaccinating

The increase in parents choosing to follow alternate vaccination schedules is concerning for multiple reasons, but primarily because when vaccinations are not given on time children are left more vulnerable to serious diseases (2). Children who receive no vaccinations are at especially high risk for contracting vaccine-preventable diseases. Pertussis outbreaks, for example, have been well-studied due to their frequency of occurrence. Evidence has shown that the risk of pertussis is higher among unvaccinated children compared to those who were vaccinated (11),(12). A study of New York state counties found vaccine-exempt children had a 14 times higher mean incidence of pertussis compared to vaccinated children (9). At the state level, states with more lenient vaccination exemption policies are associated with higher pertussis incidence compared to states with stricter exemption policies, and pertussis incidence was twice as high in states only offering religious exemptions as compared to states that also offer personal belief exemptions (10). Children who are unvaccinated are also more vulnerable to measles, which is concerning given that, despite high levels of vaccination, is it estimated that over 12% of U.S. children under 17 are susceptible to measles (13). A review of literature on measles found that over half of cases had no measles vaccination despite being eligible for vaccination (14). Additionally, it was found that 75% of cases in a large measles outbreak were intentionally unvaccinated (15). Evidence has also shown that in outbreak settings, vaccinated children have much lower attack rates of varicella compared to unvaccinated children (16).

While there is substantial evidence supporting the association between vaccination refusal and infection with vaccine-preventable disease, there is also evidence of the same association among undervaccinated children. On-time vaccination is essential because delayed vaccination widens the window of time when children are not fully immunized against disease, increasing their risk of illness (2). In a case-control study of children with pertussis, a dose-response relationship was found between the risk of pertussis and the number of Diphtheria Tetanus and Pertussis (DTaP) vaccinations received by the child. The same study found that over 36% of all pertussis cases studied were attributable to undervaccination (17).

Apart from the concern of undervaccinated and unvaccinated children being left vulnerable to serious diseases, there is also the risk of putting others who are too young or too sick to be vaccinated at risk. Herd immunity, or when a high enough proportion of the population is vaccinated so that vaccine preventable diseases are not able to spread as easily throughout the community, is an important part of protecting those who are not able to get vaccinated. Those who are not able to get vaccinated are often individuals with conditions that impact their immune system, meaning that their outcomes may be worse if they were to get one of these diseases. When parents of healthy children choose not to vaccinate or not to fully vaccinate them, the proportion of people vaccinated is not high enough to have herd immunity and the disease is more easily able to spread in the population (18). Furthermore, there has been evidence of nonvaccinated children spreading disease to children who were fully vaccinated. In an analysis of Colorado measles cases, it was found that 11% of vaccinated cases were exposed to measles from an unvaccinated contact, with this being a low estimate (12). This is because even highly effective vaccines are not perfect. The measles vaccine, for example, is estimated to be 93% effective at preventing measles after one dose and 97% effective after two doses. However, because it is not 100% effective there are still some fully vaccinated children who, if exposed, could become sick from measles. This underscores the importance of high vaccination coverage in a population to prevent the virus from being able to spread (19). Additionally, the vaccination of certain populations may play a greater role in herd immunity than others. Schools have an important role in the spread of many respiratory diseases, which is important considering the majority of childhood vaccine doses are given to school-age children, suggesting an increased importance of compliance in limiting community spread (20).

Another documented concern with undervaccination is that children who follow an alternative vaccine schedule are less likely to ever become fully vaccinated. Among a cohort of New York state children, those who followed a routine vaccination schedule were 7 times as likely to be up to date than children following an alternative schedule. Furthermore none of the children whose parents selectively refused certain vaccines were fully vaccinated by 9 months of age (5). This trend continues as the child gets older, as it was found that by 24 months of age children of parents who intentionally delayed vaccination were significantly less likely to be fully vaccinated and catch-up vaccination coverage was significantly lower compared to children who were vaccinated according to the routine schedule (21). While vaccine delays at the first visit contribute to incomplete vaccination at two years, vaccination delays at subsequent visits are also important contributors to incomplete vaccination (22). A study looking at DTaP administration found an increased risk of delay or missing the forth dose among those who had a delay in their third DTaP dose (23). Additionally, the proportion of children who have delays increases in later visits, suggesting the importance of each visit to remaining on schedule (22).

Characteristics of Under- and Unvaccinated Children

There are certain characteristics that are more likely to be associated with children who do not follow the routine immunization schedule. Importantly, these characteristics tend to be different for children who receive no vaccines versus those who have vaccine delays. Nationally, children who were unvaccinated were more likely to be white, male, have a married, college-educated mother, and live in a household that makes more than $75,000 a year. They were also more likely to have a mother who expressed concerns about the safety of vaccination. In contrast, undervaccinated children were more likely to be black, have a single mother who was not college-educated, and live in an urban setting close to the poverty line (24),(25). A national study looking at maternal characteristics of undervaccinated children found additional characteristics of these mothers included having multiple children and being eligible for the Women, Infants, and Children (WIC) program but not being enrolled (26). Specifically for rotavirus vaccine, children were more likely to be unvaccinated if their mothers did not graduate from college, their household had at least four children, their vaccines were given in a non-private clinic, or they had ever been uninsured. Conversely, children whose mother had a college degree or lived in a household with an income of over $75,000 were more likely to have a missed opportunity for rotavirus vaccination (a healthcare visit where a DTaP was given but not rotavirus vaccination), further illustrating the differences between undervaccinated and unvaccinated children (27).

Reasons for Vaccine Refusal and Alternate Schedules

There has been ample work looking into why children are not being vaccinated on time or at all. In general, there are many factors that contribute to the reasons that parents are not vaccinating their children. A major theme among parents is a concern about the effects of vaccines, with parents of children with vaccine exemptions being more fearful of the safety of vaccinations and having a lower concern about the severity of vaccine preventable diseases as compared to parents of vaccinated children (28). Parents who express hesitancy towards their child receiving multiple injections per visit report primarily being concerned about the amount of pain their child would feel, the side effects of multiple injections, and skepticism of the effectiveness of the vaccinations, which could contribute to the appeal of alternate vaccination schedules to parents (29). Importantly, concerns about vaccine safety and necessity were different among parents who refused vaccination and parents who delayed vaccination (25). In addition to fears of pain and side effects, parents whose children had at least one immunization that was over six months overdue reported being confused by the immunization schedule and not knowing when they were supposed to return for future immunizations, as well as having difficulties finding time to bring their child for immunizations (30).

A common theme of why children are not fully or timely vaccinated relates to the immunization provider. One common factor among parents is trust in their child's healthcare provider. Parents who do not report trusting their pediatrician are less likely to vaccinate their child, with one survey finding that parents who refused vaccinations and those who delayed their child's schedule were 34 and 8 times, respectively, more likely to express distrust in their pediatrician than parents whose children were fully vaccinated (31). Conversely, parental approval of vaccination has been demonstrated to be related to provider recommendation (29). Furthermore, among parents who changed their minds about delaying vaccination or not getting a vaccination for their child, the most common reason for doing so was assurances from their health care provider (25). There is also evidence suggesting that a lack of a regular healthcare provider or having two of more healthcare providers is associated with vaccine delay, emphasizing the important role that providers may play in on-time immunization (3),(32).

Measures of Vaccination Status

Contingent on all these findings of vaccination trends and demographics is having an accurate way to measure vaccination status. There are numerous important considerations around measuring vaccination status which, when changed, can tell a different story about a child's immunization history. One way to assess childhood vaccination status is to look at the child's completion of the ACIP's 4:3:1:3:3:1 immunization schedule by 24 months of age. Analysis of 2012 data found that by 24 months approximately 70% of children had completed this vaccination series. However, when looking at the completion of each vaccination series individually, there are important differences. At 24 months, completion rates ranged from 92% for polio vaccination (IPV) to 68% for rotavirus vaccination (RV). Completion rates ranged even further when looking at different timepoints, with completion at 18 months being the lowest (33). Additionally, this method of assessing completion does not reflect any time that children were not up to date in those 24 months and thereby vulnerable to disease. For these reasons, it is important to look at vaccination status in a way that accounts for the timing of individual doses for each immunization.

One way to do this is to assess immunization status at different milestones in the first few years of life. By doing so, one is able to determine where children are falling behind on their immunizations, when they are catching up, and where there are missed opportunities. Robison et al. used this approach to examine vaccination coverage in children enrolled in the Oregon Health Plan with records in the Oregon Immunization Information System. Through this analysis, they were able to show that the majority of children wavered between being up to date and not throughout the first two years of life as well as the contribution of provider visits where a recommended vaccination was not given, leading to the ability to identify areas for intervention (34).

Another strategy is to classify vaccination behavior schedule types based on patterns of vaccination to assess coverage. Nadeau et al. used this method to assess vaccination status of New York State children through the first nine months of life. Children's schedule adherence was assessed based on the timing of their first vaccination visit and the number of vaccinations received. Schedules were classified as routine, alternative, which included categories of restrictive schedule only, selective schedule only, or restrictive and selective refusals, or unknown for children whose schedule did not fall into one of the other categories. By categorizing children into schedules they were able to examine associations with up-to-date status and quantify intentional deviations from the routine schedule (5). Hargreaves et al. performed a similar analysis of categorization of schedule with nationwide immunization data. Their analysis allowed them to look at associations between demographic variables, vaccination patterns, and up-to-date status, giving insight on where to target interventions (4).

In a 2005 paper, Luman et al. developed a metric to help account for all of the time that a child was undervaccinated throughout the first few years of life. Luman et al.'s undervaccinated metric accounted for the days of life between when each recommended vaccine dose should have been administered based on the ACIP vaccination schedule and the day that dose was actually received. Days undervaccinated was calculated by summing all days the child was unvaccinated for at least one dose of any vaccine, which is an important step in understanding the timing of vaccination as a part of vaccination status (32).

However, what the Luman et al. measure does not account for is the number of doses that the child was undervaccinated for each day, and therefore does not measure the magnitude of undervaccination (for example, if a child was undervaccinated for just one vaccine versus multiple on each day). To account for this, Glanz et al. modified the Luman et al. measure to create a measure of average days undervaccinated. This was done by calculating the days undervaccinated for each dose of each vaccine in the first 24 months of life, summing all of the days undervaccinated, and dividing this by the number of vaccines that the child should have received according to the ACIP schedule (7). This measure is advantageous in that it captures the amount of time that children were not fully immunized and therefore vulnerable to disease while accounting for the number of doses that were not given according to schedule.

Thesis Rationale

While the work of Glanz et al. illustrates important trends in undervaccination, there is a need for an expansion of these analyses. To date, there has been no national-level analysis of average days undervaccinated. Prior analyses have looked at trends in undervaccination but there is a need to extend current work using up-to-date, national-level immunization data to help illustrate national trends in undervaccination. Additionally, existing literature describing characteristics of undervaccinated children is older and may no longer be reflective of current demographic associations, creating the need for an updated analysis (24–26). As the influence of providers on childhood immunization decisions has been demonstrated, this analysis will focus on whether there is an association between the number of providers a child sees and his/her average days undervaccinated, as well as a comparison of children who are fully vaccinated versus those who have any days undervaccinated. Understanding associations between provider and demographic factors and undervaccination can point to important areas for intervention to help increase on-time vaccination.

Introduction

Vaccination is one of the great public health achievements, preventing disease, morbidity, and mortality. Vaccine coverage among children in the United States is generally high, with an estimated 70% of children ages 19 to 35 months being up to date on their recommended vaccines (35). However, parental concerns of vaccine safety and questions of their necessity have led to increased hesitancy to vaccinate according to schedule, resulting in vaccination delays (36). Additionally, many families face economic and structural barriers to getting their child vaccinated, reducing on-time vaccination (37). A 2005 estimate found that nationally approximately 74% of children had delays for at least one vaccination during the first 24 months of life (32). The trend of vaccine delay and refusal is concerning because when children are not vaccinated on time they are left vulnerable to serious diseases and the risk of outbreak increases (2).

It is therefore important to be able to accurately measure vaccination status and coverage among different populations and over time to be able to implement effective public health interventions. Numerous metrics have been used to assess vaccination coverage among children. One method is to consider whether or not a child is up to date on their vaccinations at a certain age to determine vaccination status (33). However, this method does not illustrate whether the child had periods of life in which they were not fully vaccinated. Other methods have classified vaccination patterns into schedules based on the timing and number of doses received at each visit (4,5). In order to assess how much time a child has not been fully vaccinated, metrics have been created to account for every day that a child is undervaccinated (7,32). These measures are much more sensitive to vaccine delay than others, and as such are not directly comparable. Average days undervaccinated (ADU), a metric that accounts for every day of life not vaccinated for each vaccine dose, has only been used to assess vaccination status in a cohort of children from certain managed care organizations (7). Therefore, there is a need to test this metric on a national level.

To address this, we used data from a 2017 nationally-representative survey of U.S. children aged 19 – 35 months using provider-verified immunization data. This allowed us to assess ADU on a national level and provide current estimates of factors associated with vaccination delay.

Methods

Study Population

All analyses were conducted using data from the 2017 National Immunization Survey – Child (NIS- Child), a public use dataset. The National Immunization Survey is conducted by the National Center for Immunization and Respiratory Diseases in the Centers for Disease Control and Prevention and provides population and state and local area estimates of vaccination coverage among children 19 – 35 months. The NIS – Child measures coverage for ten recommended vaccines through a two-part data collection process. Participants are selected via random digit dialing of cellphones to identify households with children who are 19 – 35 months or will be shortly after being selected to participate and live in the United States. Selected households that are deemed eligible are administered a telephone survey answered by a parent or guardian of the eligible child regarding demographics, socioeconomic factors, and vaccination history of the child. The parent or guardian is also asked for consent to contact their child's healthcare provider to verify immunization history. If permission is granted, an immunization history questionnaire is sent to providers that includes questions on the dates that the doses of all vaccinations were received, the number of doses, and the vaccine type (38).

For the purposes of this analysis the study population was children living in the United States between the ages of 19 – 35 months who had adequate vaccination provider data. Adequate provider data was determined by a predetermined variable in the NIS – Child 2017 dataset. The analysis was limited to those with adequate provider data so that dates of each vaccination dose were known, which were necessary to calculate ADU. Of the 28,465 children in the dataset, 15,333 had adequate provider data and were therefore eligible for inclusion in the analysis (53.9%).

Study Variables

Average Days Undervaccinated

The primary outcome of interest in this analysis was average days undervaccinated – a measure that subtracts the time between when a child should have received a dose for each vaccine based on the recommended schedule and when they actually received that dose for each dose that they were eligible to receive and divides this cumulative total by the number of vaccinations the child should have received in the first 24 months of life. For this analysis, eight vaccines were included in the calculation of ADU: Diphtheria, tetanus, and acellular pertussis (DTaP), hepatitis B (HepB), *Haemophilus influenzae* type B (Hib), pneumococcal conjugate (PCV), measles, mumps, rubella (MMR), inactivated poliovirus (IPV), varicella (VAR), and rotavirus (RV), based on the recommended immunization schedule for children (39). A multi-step process was used to create the ADU variable. All values involved in this calculation for each dose (minimum acceptable age for the dose, minimum acceptable age between doses, and age in days when count for undervaccination begins) were based off of the values used by Glanz et al. in their ADU calculation (7). These values are outlined in Table 1. The child's vaccination dates were provider-confirmed in the immunization history questionnaire. The NIS – Child 2017 does not contain actual vaccination dates for each dose, but instead a pre-calculated age in days at vaccine receipt which was used to represent the date of vaccination.

The first step in creating the ADU variable was to determine whether each dose of vaccine that the child received was a valid dose. A valid dose was one that was given on or after the minimum acceptable age of life and had at least the minimum acceptable interval of days between the current dose and the previous dose (Table 1). A new variable was created for each vaccine dose that holds the days of life on which that dose was received on if it was a valid dose, and missing if the dose was missing or not valid.

To calculate ADU, an age in days when counting for undervaccination stops is needed. The NIS – Child data does not contain the actual age in days of the child at the time of interview. Instead, the data have the child's age group, categorized as 19 – 23 months, 24 – 29 months, or 30 – 35 months. Based on the Glanz et al. methodology, 24 months of life was represented as 730 days. Therefore, in order to not penalize children who were not yet 24 months at the time of the survey for not being vaccinated on days they were not alive we created a maximum days of life variable that represented the last day that the child could have been vaccinated. For children in the 19 – 23 months age group, the oldest age at which they received a vaccine was calculated. If the days of life on which the child received their last vaccine was greater than 730 days their maximum age day was capped at 730. If the day of life that the child received their last vaccine was less than 570 days (used to represent 19 months), their maximum age day was capped at 570. Otherwise, if their age at their last day of vaccination was between 570 and 730 days, their maximum age day was set to the day of their last vaccination. This was done to create a conservative estimate of the age of these children. For children who were in the 24 – 29 or 30 – 35 months age groups the maximum age day was set to 730 days.

The valid dose for each vaccine was checked to ensure that it was not greater than the maximum age variable. If a dose was greater than the maximum age days then that dose was set to equal the maximum day value. The exception to this was for any doses of rotavirus vaccine. Since rotavirus vaccine should not be given after 252 days, count for undervaccination for rotavirus ended at 252 days of life.

Next, the start and end of the delay for each dose were determined. The delay start was set at the age when count for undervaccination begins for each dose if the vaccination was received after that date or missing, and set to missing if the dose was received before that date, indicating an on-time dose. If the dose was missing, the undervaccination end date was set at the maximum age day. Otherwise, the delay end date was set at the day that the dose was actually received by the child. For example, the first dose of DTaP is recommended to be given at 2 months of age. The age that counting for undervaccination beings for the first dose of DTaP is at 93 days. For a child who received their first DTaP dose at 100 days, the delay start would be 93 days and the delay end would be 100 days. Alternatively, a child who did not receive their first DTaP dose would also have a delay start age of 93 days but would have a delay end of 730 days, since for their entire first 24 months of life, excepting the first 92 days, they were undervaccinated for DTaP. A child who received their first DTaP dose at 90 days would have no start delay or end delay date because they were never undervaccinated for the first dose of DTaP.

This same calculation was repeated for each dose of each vaccine. The only exception to this was for the RV vaccine. The RV vaccine is available in both a two-dose and a three-dose formulation, based on the vaccine type. The vaccine type for the first RV dose was used to determine whether the child should have gotten two or three doses. Children whose first RV dose was Rotarix were determined to only need two doses, whereas for children whose first RV dose was Rotateq or an unknown type, a three-dose series was deemed necessary based on CDC recommendation (39). If a child was determined to only need two doses of RV, no delay was calculated for lacking a third dose.

A series of arrays were then used to identify each day of life for which the child was undervaccinated for each vaccine series and then sum the number of unique days undervaccinated. This was done in order to avoid double counting days in the case of children who were so delayed in a dose that the period in which the dose was given overlaps with the period for the next dose. If the child who received their first DTaP at 100 days received all of their other DTaP doses on time, their total days undervaccinated for DTaP would be 8 days (100 days at vaccination – 92 days). Finally, average days undervaccinated was calculated by summing the total days undervaccinated for each of the eight vaccine series and dividing by eight. A secondary outcome variable, whether or not the child had any vaccine delay, was created by dichotomizing the ADU variable into those with zero ADU (no vaccine delay) and those with an ADU of greater than zero (was undervaccinated for some period of time).

Predictor Variables

All predictor variables were selected prior to analysis, based on availability of the NIS – Child dataset and important predictors of vaccination behaviors as identified by previous research. The primary predictor of interest was the number of providers that the child saw. For this analysis, we chose to use the number of providers that the parent reported, as opposed to the number of providers who returned a survey for the child. Covariates of interest included child's sex, race and ethnicity, and firstborn status, maternal characteristics (highest level of education, age, and marital status), household poverty status, child's insurance type, and the vaccination provider facility type. All covariate information was obtained through the parent or guardian in the phone survey. Poverty status, which was categorized as "At or above poverty level, income > $75,000", "At or above poverty level, income ≤ $75,000", "Below poverty level", or "Not determined" was collapsed into at or above poverty level, below poverty level, or not determined for this analysis. Some individuals were missing data on provider facility type. Those with missing facility type data or with a poverty level not determined were excluded, resulting in 14,458 observations used in the final analysis.

Data Analysis

All analyses were conducted using SAS 9.4 (Cary, NC). SAS procedures that incorporate survey weights were used to account for the sampling methods used in the survey. The sampling and survey methods are detailed in the NIS – Child 2017 Data Users Guide (40).

Weighted frequencies and p-values comparing covariates for children who had zero days undervaccinated with those who had at least one day undervaccinated were calculated using PROC SURVEYFREQ. Since all children who had no vaccine delay had at least one vaccination provider, significance for number of providers was calculated excluding those with no providers. Weighted mean, median, and inter-quartile range (IQR) ADU for each covariate of interest were calculated using PROC SURVEYMEANS. Only children with at least one day undervaccinated were included in the calculation of these statistics, leaving a total of 10,115 children. In order to have more robust data, the number of providers was categorized from 0, 1, 2, or 3+ to 0, 1, or 2+ for the purposes of modeling. Because all those who had zero providers also had missing data for provider facility they were deleted, leaving only those with 1 or 2+ providers. Given issues around fragmented medical care impacting on-time vaccination, the main exposure for our regressions were the number of vaccination providers that a child saw, but other variables of interest were added to assess relative effects (41,42). Associations between covariates of interest and whether or not a child had any vaccine delay were assessed using a Poisson regression model. The model was built using a backwards elimination strategy and a significance cutoff of a p-value less than 0.05. Prevalence ratios (PRs) and 95% Confidence Intervals (95% CI) were calculated using PROC GENMOD with a repeated subjects statement to properly account for the survey weights, based on the methods described by Hale et al. (43). A linear regression using PROC SURVEYREG was performed to assess the impact of demographic, socioeconomic, maternal, and provider variables on ADU. The linear regression was restricted to those who had at least one day undervaccinated, resulting in 9,419 observations used in this model.

Ethics

This analysis was conducted using previously collected, publicly available data that contain no protected health information. The analysis was determined to not require Emory IRB review because the research does not involve human subjects and is not a clinical investigation.

Results

Characteristics of Those With and Without Vaccine Delay

In total, data from 15,333 children with adequate provider data were included in the analysis. Count, weighted count, and weighted percentage for demographic, socio-economic, and provider characteristics stratified by whether or not a child was undervaccinated for any days of life are summarized in Table 2. Overall, 68.2% of children in the study population had at least some vaccine delay. The percentage of children with a vaccine delay increased as the number of vaccination providers that a child saw increased from 1 to 2 to 3 or more providers (66.7%, 69.8%, 79.2%, respectively). Certain subgroups had a higher proportion of having any vaccine delay, including children who were uninsured (82.3%) and those whose mother had less than 12 years of education (78.6%). In contrast, groups who had a high proportion of no vaccine delay were children who had only private insurance (42.2%), those whose mothers were a college graduate (40.7%), and children who were firstborn (37.6%).

Mean ADU

Statistics for weighted mean, median, and IQR ADU by covariates of interest are summarized in Table 3. Overall, for children who had at least one day undervaccinated the mean ADU was 94.3 days (SD = 2.5), with a median of 48.6 days and an IQR of 19.1 to 107.5 days. Children who reported having seen 0 vaccination providers had the highest

ADU (mean ADU [SD]: 457.1 [4.7]; median: 396.1). Mean ADU also increased as the number of vaccination providers increased from 1 (mean ADU [SD]: 85.9 [2.7]; median: 45.4), to 2 (mean ADU [SD]: 101.6 [6.0]; median: 49.6), to 3 or more providers (mean ADU [SD]: 111.5 [8.3]; median: 58.4). Children who were uninsured also had a high ADU relative to other subgroups (mean ADU [SD]: 166.3 [11.4]; median: 99.4), although the range of ADU for those who were uninsured was wide (IQR: 36.0, 315.6). Subgroups with the lowest ADU were children whose mother was a college graduate (mean ADU [SD]: 74.2 [SD: 3.4]; median: 38.4), children who had private insurance (mean ADU [SD]: 76.2 [4.1]; median: 38.1), and those who saw only private providers (mean ADU [SD]: 77.4 [3.4]; median: 43.7). Children who were firstborn also had a low median ADU (42.4 days).

Poisson Regression

In the Poisson model, having two or more vaccination providers was associated with a slight increase in the prevalence of having a vaccine delay as compared to those with only one vaccination provider, after controlling for race, poverty status, mother's education and mother's age, firstborn status, child's insurance status, and provider facility type (PR = 1.06, 95% CI: 1.01, 1.11). There were numerous sociodemographic factors associated with having at least one day undervaccinated, including living below the poverty level (PR = 1.10, 95% CI: 1.04, 1.16), not being the firstborn child (PR = 1.16, 95% CI: 1.11, 1.21), having a mother with less than 12 years of education as compared to a mother who graduated college (PR = 1.11, 95% CI: 1.03, 1.20), and having a mother who was less than 30 years old (PR = 1.08, 95% CI: 1.03, 1.13). As compared to having only private insurance, all other insurance types (any Medicaid, other insurance, uninsured) were significantly associated with an increased prevalence of having any vaccine delay, with uninsured children having the highest increased prevalence (PR = 1.27, 95% CI: 1.17, 1.38). Hispanic children had a slightly decreased prevalence of having any vaccination delay as compared to non-Hispanic white children (PR = 0.93, 95% CI: 0.87, 0.99). Provider facility type was also associated with having at least one day undervaccinated, primarily having all hospital providers (PR = 1.14, 95% CI: 1.09, 1.20), or all military facility providers (PR = 1.18, 95% CI: 1.03, 1.35) as compared to all private facility providers (Table 4).

Linear Regression

There was also an association found between the number of providers and many of the covariates of interest and ADU in the linear regression. The full model results of the linear regression model are presented in Table 5. The model had an R-square value of 0.045 and a p-value of <0.001. Children with two or more vaccination providers were predicted to have an 18.7 day greater ADU than children with only one vaccination provider. Not being the firstborn child was associated with a 11.1 day greater ADU than children who were firstborn. Mother's education status was the only maternal variable significantly associated with ADU, with both children of mothers who had less than 12 years of education and those who had 12 years of education predicted to have a higher ADU than children of college educated mothers (27.8 days, 20.8 days, respectively). Compared to children who visited all private facilities for their vaccinations, children who visited all hospital facilities had a higher estimated ADU by 34.1 days. The predicted ADU for uninsured children was 41.5 days higher than for children with only private insurance.

Discussion

There are many different measures that have been used to attempt to assess the vaccination status of populations, including up-to-date status at a certain age (33), assessing vaccination at certain milestones (34), vaccination patterns (4,5), and days undervaccinated (7,32). However, to date, there is no universal metric to do so. Average days undervaccinated, a measure developed by Glanz et al. and based off of the concept of days undervaccinated used by Lumen et al., is a promising method of assessing vaccination status as it accounts for the timing of every dose of every vaccination and gives a single number to represent this for each child (7,32). Currently, the ADU metric has only been used to look at vaccination status in limited settings, but no national-level assessment has been conducted (7). This analysis expanded on that work to give an up-to-date, nation-wide picture of vaccination delay among U.S. children.

Estimates of Vaccine Delay

Overall, we found that 31.8% of children nationally received all of their vaccinations on time according the ACIP routine schedule, leaving 68.2% with at least one day undervaccinated. This is higher than older estimates of on-time vaccination, with data from 2000 finding only 9% of children had received all of their vaccinations on time (6). Using a days-undervaccinated approach, Luman et al. found that 74% of children were delayed for at least one vaccination in the first 24 months of life based on 2003 national data (32). Newer measures of the proportion of children following the routine schedule by Glanz et al. found that in the first 24 months of life, 47.8% of children born between 2004 and 2008 were undervaccinated for at least one day, however these data were not nationally representative (7). Attempts to classify children based on vaccination schedule found that among New York children, approximately 70% followed the routine schedule, and an analysis using 2014 NIS data found that 63% of children's vaccination patterns were consistent with adherence to the ACIP schedule (4,5). An analysis of 2017 NIS data found that 70.4% of children 19 – 35 months were up to date on the full 7-vaccine series (35). This percentage, in comparison to our finding of only 31.8% of children having no vaccine delay, illustrates that this type of measure is a more sensitive assessment of vaccination status than measuring up-to-date status at a certain timepoint as it accounts for delays over time.

While it would be useful to compare vaccination delay between years and populations, estimates of delay vary in important aspects that make accurate comparison difficult. One of these components is that the strictness of what counts as vaccination delay varies depending on the metric used. The ADU measure used in this analysis could be considered among the strictest, as children are categorized as having any vaccine delay if they had even one day of life undervaccinated. Another factor that can make comparison difficult is which vaccinations are included in assessing delay. Specifically, the inclusion of RV vaccine and hepatitis A vaccine vary between studies. Additionally, while most studies have looked at vaccination status in the first 24 months of life, not all use this endpoint. As previous work has demonstrated that children's up-to-date status fluctuates at different timepoints throughout their first few years of life, having different end-points may lead to different conclusions about overall delay (34). This illustrates the need for comparable metrics of vaccination status to be able to accurately assess trends over time and by location.

In our analysis, we found the mean ADU among all children with at least one day undervaccinated to be 94.3 days. In comparison, Glanz et al. found a mean ADU of 36 days in their analysis of children born between 2004 and 2008 in 8 managed care organizations across the U.S. (7). There are a few possible reasons that could contribute to this difference in findings. Some of this may be attributed to slight differences in ADU calculation between these two analyses that could impact mean ADU. Additionally, evidence has suggested that vaccination delay has been increasing over time (7,8). Given this, it is possible that the ADU among U.S. children has increased in the last decade. Finally, there may be true differences in the study population. The participants in the MCOs used in Glanz et al.'s study compromise approximately 3% of the U.S. population versus the weighted NIS data which is nationally representative, and therefore their population may have had different characteristics that influence vaccination status (7,38). Primarily, by the nature of being enrolled in an MCO these children have access to some form of healthcare, and therefore they may have better access to services than the general U.S. population, leading to more on-time vaccination doses. Additionally, an economic systematic review of strategies to improve vaccination coverage found that interventions in MCOs had good population reach and were cost-effective, which could also contribute to the lower ADU in this population (44). However, it is likely that there are a combination of factors that contribute to the higher ADUs among U.S. children as a whole due to the many associations we found in our analysis between provider, demographic, and socioeconomic characteristics and vaccination delay. It would be beneficial for future analyses to apply the same ADU methodology to older NIS data to be able to accurately assess changes over time in undervaccination.

Number of Providers and Vaccination Status

Due to the influence of vaccination providers and continuity of care on vaccination outcomes, our primary exposure of interest was the number of vaccination providers that a child saw. We found that there was an association between ADU and number of providers, with the mean ADU increasing from 85.9 days to 101.6 days to 111.5 days for children with 1, 2 and 3 or more vaccination providers, respectively. This supports the findings of older work that suggests a relationship between vaccination up-to-date status and consistency of providers. A study done in 2000 looking at up-to-date status for MMR vaccination at 15 months of age found that higher continuity of care, defined as minimum dispersion between providers seen, was associated with more timely MMR vaccination (41). A related concept, continuous care in the medical home, has also been examined in relation to up-to-date status. A study from 2007 defined continuous care in the medical home based off of whether the child had a regular doctor or nurse who knew the child and their health history well and if the child had received preventative healthcare in the last 12 or 24 months from that same doctor or nurse. The authors found that children without a continuous medical home were less likely to be up-to-date for all vaccinations than children with a continuous medical home (42). This study built upon the work of previous papers demonstrating an association between continuity of care and a medical home on immunization coverage (45,46).

There are multiple explanations that may contribute to the importance of continuity of care on immunization status. Previous research has found that parents report the relationship with their child's provider and the recommendations given by the provider as a main factor in their vaccination decisions (25,29,31). Given this, it is plausible that parents of children who have had only one vaccine provider have had time to develop a relationship with that provider and build trust, leading to more confidence in their provider's vaccine recommendations. This could be especially relevant for parents who have hesitancies about the safety and efficacy of vaccines. If the parent has an established trust with the provider and is confident that the provider understands their child's health history, they may be more likely to accept their recommendations for necessary vaccinations, as opposed to someone who they do not feel understands the needs of their child.

Continuity of care may also be an important facilitator in improving access to well-child visits. Most providers will schedule the next well-child appointment at the end of the previous visit and many have some type of reminder system to let parents know when their next visit is coming up. This is important because of the complex nature of the immunization schedule. A hesitancy questionnaire administered to eligible parents revealed the most common reason for an overdue immunization was parental confusion about the immunization schedule and when their child needed to return (30). If a child does not have a regular provider it would be on the parent to know when the next immunization visit is needed and schedule the appointments, resulting in delays. Additionally, mothers who were surveyed about their child's vaccinations listed not being able to get an appointment as a major immunization barrier (37). As there is often a wait time when providers are not able to accept new patients, children without a regular provider may have trouble getting timely appointments when they are due.

These factors underscore the benefits of increased continuity of care on immunization timeliness. The importance of medical homes has been long-established, as one of the reasons for the creation of the Vaccines for Children (VFC) program was to help facilitate vaccination within a child's medical home (45). While much of the literature supporting the importance of continuity of care on vaccine status is older and only examines up-to-date status at a certain age, our analysis shows both that this trend is still relevant and does so with a measure that accounts for the timing of vaccine delay. This suggests that continued efforts should be paid towards facilitating the ability of a child to stay with one provider throughout their childhood to help increase routine vaccine schedule compliance and lessen periods of time when a child is not fully immunized.

Additional Factors

While the number of vaccination providers that a child saw is an important predictor of undervaccination, we found that there are other factors that also have an impact. One of the most important predictors was the child's insurance type. Notably, children who were uninsured had one of the highest mean ADUs. The association between being uninsured and vaccine delay has been previously demonstrated (27,35,42). Children who had any Medicaid insurance also had a higher mean ADU (102.9 days) than those with private insurance only (76.2 days). One explanation for these trends is likely a lack of access to providers. The options for getting vaccinated are more limited for children without any insurance, making staying up to date with immunization visits difficult. Similarly, there are many providers who do not accept Medicaid as a form of payment.

The mean ADU was also much higher for children below the poverty level (108.6 days) than for children above the poverty level (86.5 days). Given that 86% of children living below the poverty level were on Medicaid and an additional 3% were uninsured in our analysis, these children may experience similar problems with access to vaccination. Children living below the poverty level are more likely to face additional barriers to staying up to date on vaccinations, including access to transportation to get to a provider or the ability for a parent or caregiver to take off work to bring the child to their appointments. Parents of children who are uninsured may have no way to get vaccinations for their children other than to pay out of pocket, which could be a financial hardship for those living below the poverty line. Although the VFC program was designed to help reduce these financial barriers by providing free vaccines, there are still issues of accessing and understanding the program, contributing to continued lower rates of coverage among these populations (35). These findings point to the need to expand access to affordable insurance so that parents have ample access to providers in their area and can afford to ensure their child is vaccinated on time.

Maternal characteristics, including having a mother who was less than 30 years old and having a mother who was not a college graduate were also associated with an increased likelihood of being undervaccinated. Associations between maternal education and undervaccination have been previously described, and may be due in large part to being more likely to be below the poverty line, facing these same barriers (26). Children with a mother who was less than 30 had a higher mean ADU than children with older mothers and had a slightly increased prevalence of vaccine delay in the Poisson model, however in the linear regression model children with a mother under 30 had a slightly lower expected ADU, although this finding was not significant. This finding may be due in part to the dichotomization of maternal age. A study of 2001 – 2003 NIS data found that maternal age was a significant predictor of up-to-date vaccination coverage, with coverage the lowest among mothers who were 17 years old and increasing by approximately 1.8% per year of maternal age through 26 years. After 26 they found no significant increase as maternal age increased (47). Teenage mothers may suffer from financial difficulties, lack of social support, and lack of knowledge that all contribute to being less likely to have their child vaccinated on time. However, as mothers get older but are still in their twenties, these social factors may become less relevant and other protective factors may play more into vaccination decisions. By dichotomizing maternal age, these important distinctions may have been masked.

Firstborn status of the child has been shown to be associated with a higher likelihood of following the routine vaccination schedule (4). Not being the firstborn child was a significant predictor of any vaccination delay and associated with increased ADU in our models. This finding was independent of the effect of mother's age, as almost half of children with a mother less than 30 were firstborn in our analysis. One explanation for the association between firstborn status and ADU could be an increase in logistical barriers to immunization with more than one child. Mothers who participated in a survey on immunization expressed that as they had more children there were more barriers to getting to vaccination appointments, such as finding childcare for their other children, and as a result their views about immunization became more lax as their families grew bigger (37). Another potential explanation for this association could be a lack of negative experience with vaccination. A first-time mother may have every intention of fully vaccinating her child and do so for a while. But if the child was to experience some type of negative reaction sometime after vaccine administration she might be more hesitant about vaccination and choose to follow an alternate vaccination schedule for her future children or not vaccinate them at all. This would result in her children who are not firstborn having a higher ADU. Although data examining reasons behind this association are limited, a study of Australian parents found that 63% of parents who reported an adverse event following influenza immunization stated that they would be hesitant to or refused to vaccinate their children against influenza in the future (48). To help address this, providers should work with parents who have had a potential adverse vaccination event to help them assess the importance of vaccination and the potential health risks of vaccine-preventable diseases in relation to possible side effects.

Strengths and Limitations

This study has multiple strengths, including the large sample size. Another strength is the sampling method that was used to collect the data, allowing us to calculate weighted statistics that are representative of the U.S. population. Additionally, we were able to calculate a measure of vaccination status that accounts for each day of life a child is undervaccinated for each dose they should have received using provider-verified dates, allowing us to illustrate the vaccination delay in the U.S. using recent data.

This study also had several limitations. Because we used previously collected data, we were limited to the variables provided in the dataset. For instance, it may have been illustrative to have mother's age available as a continuous variable to assess associations with ADU. We also lacked data on variables that could have been of interest, such as whether the child was intentionally unvaccinated or undervaccinated due to parent refusal. This is especially important given the reported differences in demographic and socioeconomic characteristics between children who are undervaccinated and children who are unvaccinated (24). Additionally, this study was limited to children who had provider-verified data, which was only 53.9% of the total sample. Excluding these children may result in bias if these children have different vaccination behaviors that may impact their ADU. Finally, because we calculated a measure of vaccination status that has only been used in one other paper, the results from this analysis are not directly comparable to other studies.

Conclusion

Our results provide a current look at vaccination coverage in the U.S. through a metric that accounts for the time a child was left vulnerable to disease. This study highlights many important factors associated with vaccine delay including seeing multiple vaccination providers, being uninsured or on Medicare, living below the poverty level, and not being a firstborn child. Understanding these associations is important in providing areas to target interventions, such as increasing continuity of care and decreasing children who are uninsured. Expanded use of the ADU metric in future studies can help illustrate vaccination trends and this, along with public health intervention, can be used to improve timely adherence to the routine vaccine schedule in the U.S.

Public Health Implications

As issues of vaccination hesitancy and barriers to immunization continue to impact vaccination coverage in the U.S., it is essential to be able to assess vaccination status on a national level. Our analysis did so using ADU – a metric that accounts for every day of life that a child is not appropriately vaccinated for each vaccine dose. We found that nationally U.S. children between the ages of 19 and 35 months had a mean ADU of 94.3 days, however the ADU varied greatly among different populations. This indicates not only a national need to address vaccination delay to decrease the ADU, but also gives insight into populations to specifically target for public health intervention. By helping to improve understanding of and address concerns related to the vaccination schedule, parents may be more likely to vaccinate their children on time, as opposed to following alternate schedules. An increase in continuity of care, which can help build trust between parents and providers, may also help address this. Additionally, reducing barriers to vaccination faced by those living below the poverty level and without insurance may help increase on-time vaccination among parents who want to follow suggested schedules but lack the means to do so. Because we found many factors to be associated with vaccination delay, it is important that public health interventions employ a multi-faceted approach to address these barriers. Additionally, we found that almost 32% of children were vaccinated on-time for every dose. Further study of who these children are and what motivated their parents to make these vaccination decisions may help us understand what works and how these strategies can be employed more broadly. This may help to increase the number of children nationally who experience no vaccine delay and as such are as protected from disease as much as possible throughout every day of their childhood.

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Tables

Table 1. Vaccination timing by dose *

Vaccine/ Dose	Recommended Age (months)	Minimum acceptable age with 4 day grace period (days)	Minimum accetable interval between doses with 4 day grace period (days)	Age when count for undervaccination begins (days)
Hepatitis B (HepB)				
1	0 to 2	0		93
2	1 to 4	24	24	154
3	6 to 18	176	38	580
Roatvirus (RV)				
1	2	38		93
2	4	66	24	154
3**	6	94	24	215
Diptheria, Tetanus, Pertussis (DTaP)				
1	2	38		93
2	4	66	24	154
3	6	94	24	580
Haemophilus influenzae type b (Hib)				
1	2	38		93
2	4	66	24	154
3	6	94	24	215
4	12 to 15	361	52	580
Pneumococcal conjugate (PCV 13)				
1	2	38		93
2	4	66	24	154
3	6	94	24	215
4	12 to 15	361	52	589
Inactivated poliovirus (IPV)				
1	2	38		93
2	4	66	24	154
3	6	94	24	580
Measles, mumps, rubella (MMR)				
1	12 to 15	361		489
Varicella				
1	12 to 15	361		489

*Age cutoffs based on cutoffs used by Glanz et al.

** 2-dose series for Rotarix, 3-dose series for RotaTeq or unknown

Table 2. Demographic, socioeconomic, and provider characteristics comparing children who received all vaccines on time versus those with any vaccine delay

	Received all Vaccines on Time			Any Vaccine Delay			PR > Chisq
	N	Weighted N	%	N	Weighted N	%	
Total	5,218	1,834,873	31.76	10,115	3,942,862	68.24	
Sex							
Female	2,562	923,881	32.74	4,952	1,898,140	67.26	0.1846
Male	2,656	910,992	30.82	5,163	2,044,722	69.18	
Race							
Hispanic	989	475,698	30.67	2,180	1,075,086	69.33	0.005
Non-Hispanic White	3,222	913,851	33.62	5,736	1,804,282	66.38	
Non-Hispanic Black	287	184,525	24.99	815	554,003	75.01	
Other races and multiple races, non-Hispanic	720	260,799	33.86	1,384	509,490	66.14	
Firstborn Status							
No	2,796	982,200	27.99	6,514	2,526,316	72.01	<.0001
Yes	2,422	852,673	37.58	3,601	1,416,546	62.42	
Mother's Education							
< 12 years	381	197,358	21.35	1,258	726,821	78.65	<.0001
12 years	636	364,556	26.48	1,867	1,012,369	73.52	
> 12 years Not College Grad	1,027	385,220	29.73	2,612	910,518	70.27	
College Grad	3,174	887,740	40.71	4,378	1,293,154	59.29	
Mother's Marital Status							
Currently Married	4,169	1,289,464	35.12	7,052	2,382,560	64.88	<.0001
Never married, widowed, divorced, separated, deceased, or living with partner	1,049	545,410	25.90	3,063	1,560,302	74.10	
Mother's Age							
≤ 29 years	1,347	573,505	25.88	3,718	1,642,345	74.12	<.0001
30 years or older	3,871	1,261,368	35.41	6,397	2,300,517	64.59	
Poverty Status							
At or above poverty level	4,270	1,366,068	36.81	7,122	2,345,045	63.19	<.0001
Below poverty level	769	346,234	20.88	2,568	1,312,079	79.12	
Unknown poverty status	179	122,571	30.02	425	285,738	69.98	
Child's Insurance Status							
Private Insurance Only	3,319	1,013,527	42.15	4,524	1,391,013	57.85	<.0001
Any Medicaid	1,481	690,038	24.98	4,233	2,072,553	75.02	
Other insurance	330	103,162	22.83	1,007	348,645	77.17	
Uninsured	88	28,146	17.72	351	130,650	82.28	
Provider Facility Type							
All public facilities	429	192,955	25.91	1,279	551,692	74.09	<.0001
All hospital facilities	795	194,403	24.83	1,601	588,405	75.17	
All private facilities	3,195	1,169,456	36.73	5,123	2,014,625	63.27	
All military facilities	78	46,821	22.59	320	160,484	77.41	
Mixed	721	231,238	29.15	1,502	562,031	70.85	
Number of Providers							
0	-	-	0.00	158	31,800	100.00	
1	3,765	1,349,920	33.33	6,826	2,700,622	66.67	0.0001*
2	1,231	425,274	30.20	2,520	983,039	69.80	
3+	222	59,679	20.79	611	227,401	79.21	

*Chi-square for number of providers calculated excluding children with 0 providers

Table 3. Average Days Undervaccinated by demographic, socioeconomic, and provider characteristics among children with at least one day undervaccinated

	N	Weighted N	Mean	S.D.	Median	25th Percentile	75th Percentile
All	10,115	1,834,873	94.28	2.47	48.61	19.07	107.48
Sex							
Female	4,952	1,898,140	94.62	3.30	49.36	19.24	105.55
Male	5,163	2,044,722	93.96	3.60	46.16	18.93	109.29
Race							
Hispanic	2,180	1,075,086	93.92	6.28	47.40	18.79	117.88
Non-Hispanic White	5,736	1,804,282	92.96	2.86	47.28	19.12	95.45
Non-Hispanic Black	815	554,003	101.91	6.76	51.56	21.30	117.49
Other races and multiple races, non-Hispanic	1,384	509,490	91.40	6.07	49.46	18.84	105.94
Firstborn Status							
No	6,514	2,526,316	99.99	3.29	50.32	19.56	118.56
Yes	3,601	1,416,546	84.08	3.57	42.41	18.84	83.31
Mother's Education							
< 12 years	1,258	726,821	114.06	8.21	56.39	22.34	145.61
12 years	1,867	1,012,369	105.68	4.89	51.84	20.77	136.38
> 12 years Not College Grad	2,612	910,518	94.29	3.89	49.09	19.50	108.27
College Grad	4,378	1,293,154	74.22	3.40	38.35	16.18	73.33
Mother's Marital Status							
Currently Married	7,052	2,382,560	91.84	3.24	46.10	19.45	96.34
Never married, widowed, divorced, separated, deceased, or living with partner	3,063	1,560,302	98.00	3.79	50.13	18.84	118.85
Mother's Age							
≤ 29 years	3,718	1,642,345	100.59	3.46	50.21	19.96	122.30
30 years or older	6,397	2,300,517	89.77	3.46	44.66	18.82	96.41
Poverty Status							
At or above poverty level	7,122	2,345,045	86.52	2.59	44.38	18.84	85.49
Below poverty level	2,568	1,312,079	108.55	5.42	54.26	19.79	144.31
Unknown poverty status	425	285,738	92.39	8.03	49.51	27.41	101.65
Child's Insurance Status							
Private Insurance Only	4,524	1,391,013	76.16	4.11	38.08	15.99	71.00
Any Medicaid	4,233	2,072,553	102.93	3.65	51.06	20.64	130.87
Other insurance	1,007	348,645	88.12	5.05	48.82	19.98	95.40
Uninsured	351	130,650	166.29	11.54	99.42	35.97	315.60
Provider Facility Type							
All public facilities	1,279	551,692	98.74	5.79	53.59	19.96	125.75
All hospital facilities	1,601	588,405	115.07	5.90	51.65	21.03	137.44
All private facilities	5,123	2,014,625	77.35	3.43	43.70	18.79	79.76
All military facilities	320	160,484	95.72	16.26	49.74	18.81	114.30
Mixed	1,502	562,031	86.87	5.57	45.15	19.69	101.19
Missing	290	65,625	449.89	4.76	390.68	346.39	434.96
Number of Providers							
0	158	31,800	457.07	4.72	396.07	354.48	437.66
1	6,826	2,700,622	85.88	2.73	45.40	18.86	90.94
2	2,520	983,039	101.63	5.98	49.60	18.98	131.66
3+	611	227,401	111.48	8.32	58.37	22.49	137.11

Table 4. Poisson regression results modeling the association between the number of providers a child saw and signficiant covariates and whether a child had any vaccine delay

		PR	95% CI	
Race				
Non-Hispanic White	Ref			
Non-Hispanic Black		1.01	0.94	1.08
Other races and multiple races, non-Hispanic		0.98	0.91	1.04
Hispanic		0.93	0.87	0.99
Firstborn Status				
Yes	Ref			
No		1.16	1.11	1.21
Mother's Education				
College Grad	Ref			
< 12 years		1.11	1.03	1.20
12 years		1.05	0.98	1.13
> 12 years Not College Grad		1.03	0.97	1.10
Mother's Age				
30 years or older	Ref			
≤ 29 years		1.08	1.03	1.13
Poverty Status				
At or above poverty level	Ref			
Below poverty level		1.10	1.04	1.16
Child's Insurance Status				
Private Insurance Only	Ref			
Any Medicaid		1.15	1.08	1.23
Other insurance		1.26	1.17	1.34
Uninsured		1.27	1.17	1.38
Provider Facility Type				
All private facilities	Ref			
All public facilities		1.04	0.97	1.11
All hospital facilities		1.14	1.09	1.20
All military facilities		1.18	1.03	1.35
Mixed		1.04	0.97	1.11
Number of Providers				
1	Ref			
2+		1.06	1.01	1.11

Table 5. Linear regression results modeling the impact of number of providers and other covariates of interest on the child's ADU

	Regression		**P- value**
Intercept		37.55	<0.001
Sex			
Female	Ref		
Male		0.93	0.85
Race			
Non-Hispanic White	Ref		
Non-Hispanic Black		0.22	0.98
Other races and multiple races, non-Hispanic		-0.24	0.97
Hispanic		-5.68	0.46
Firstborn Status			
Yes	Ref		
No		11.05	0.02
Mother's Education			
College Grad	Ref		
< 12 years		27.75	0.02
12 years		20.80	0.01
> 12 years Not College Grad		8.52	0.15
Mother's Marital Status			
Currently Married	Ref		
Never married, widowed, divorced, separated, deceased, or living with partner		-5.50	0.42
Mother's Age			
30 years or older	Ref		
≤ 29 years		-0.93	0.86
Poverty Status			
At or above poverty level	Ref		
Below poverty level		7.95	0.28
Child's Insurance Status			
Private Insurance Only	Ref		
Any Medicaid		13.02	0.19
Other insurance		-3.35	0.69
Uninsured		41.45	0.00
Provider Facility Type			
All private facilities	Ref		
All public facilities		6.91	0.39
All hospital facilities		34.06	<.0001
All military facilities		17.76	0.29
Mixed		-1.43	0.85
Number of Providers			
1	Ref		
2+		18.66	0.01