Failure to Complete Multidose Vaccine Series in Early Childhood

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abstract

BACKGROUND: Most early childhood immunizations require 3 to 4 doses to achieve optimal protection. Our objective was to identify factors associated with starting but not completing multidose vaccine series.

METHODS: Using 2019 National Immunization Survey-Child data, US children ages 19 to 35 months were classified in 1 of 3 vaccination patterns: (1) completed the combined 7-vaccine series, (2) did not initiate ≥1 of the 7 vaccine series, or (3) initiated all series, but did not complete ≥1 multidose series. Associations between sociodemographic factors and vaccination pattern were evaluated using multivariable log-linked binomial regression. Analyses accounted for the survey's stratified design and complex weighting.

RESULTS: Among 16 365 children, 72.9% completed the combined 7-vaccine series, 9.9% did not initiate ≥1 series, and 17.2% initiated, but did not complete ≥1 multidose series. Approximately 8.4% of children needed only 1 additional vaccine dose from 1 of the 5 multidose series to complete the combined 7-vaccine series. The strongest associations with starting but not completing multidose vaccine series were moving across state lines (adjusted prevalence ratio [aPR] = 1.45, 95% confidence interval [CI]: 1.18–1.79), number of children in the household (2 to 3: aPR = 1.29, 95% CI: 1.05–1.58; 4 or more: aPR = 1.68, 95% CI: 1.30–2.18), and lack of insurance coverage (aPR = 2.03, 95% CI: 1.42–2.91).

CONCLUSIONS: More than 1 in 6 US children initiated but did not complete all doses in multidose vaccine series, suggesting children experienced structural barriers to vaccination. Increased focus on strategies to encourage multidose series completion is needed to optimize protection from preventable diseases and achieve vaccination coverage goals.

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Ms Michels conceptualized and designed the study, planned and performed the analyses, interpreted the results, and drafted the manuscript; Drs Niccolai and Hadler revised the analysis plan, provided feedback throughout analyses, contributed to the interpretation of the data, and provided critical revisions to the manuscript; Ms Freeman and Ms Albers contributed to the conceptualization and design of the study, acquisition of data, and critically reviewed the manuscript; Drs Glanz and Daley contributed to the conceptualization and design of the study, interpretation of the data, and provided critical revisions to the manuscript; Dr Newcomer conceptualized and designed the study, supervised the analyses and interpretation of results, provided critical revisions to the manuscript, and acquired funding; and all authors approved the final manuscript and agree to be responsible for its content.

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WHAT'S KNOWN ON THIS SUBJECT: Vaccination coverage in early childhood remains below national goals. Failure to complete all doses in multidose vaccine series contributes to undervaccination and increases risk of preventable infections.

WHAT THIS STUDY ADDS: This population-based study identified risk factors for vaccination series noncompletion and suggests structural barriers to vaccination persist. If children missing only 1 outstanding dose had received that final dose, the United States would have met some vaccination coverage goals in 2019.

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The Centers for Disease Control and Prevention's Advisory Committee on Immunization Practices recommends multiple vaccine series, each consisting of 1 to 4 doses, to protect against 15 diseases in the first 2 years of a child's life.[1,2] Failure to complete all doses of multidose vaccine series is an important pediatric health problem, because undervaccination increases susceptibility to preventable outbreaks of infectious diseases. For example, missing recommended doses from the diphtheria, tetanus, and acellular pertussis vaccine series is associated with higher risk of pertussis in young children.[3–5] Moreover, un- and under-vaccinated infants are at greatest risk for severe sequalae from vaccine preventable diseases, and partially immunized carriers contribute to continued transmission of pertussis, *Haemophilus influenzae* type b, and invasive pneumococcal disease.[6–9]

Recent population-based studies on low vaccination coverage in the United States have focused on parental vaccine hesitancy as a driver of undervaccination. These studies have included examinations of specific undervaccination patterns indicative of parental hesitancy, such as a child not receiving any vaccines or selectively receiving some vaccine series but not others.[10–13] We identified few studies in the recently published literature investigating nonhesitancy causes of undervaccination.[14–16] Starting all recommended series but failing to complete multidose vaccine series suggests structural and logistical barriers to accessing vaccination services, such as care fragmentation, irregular well-child care, lack of prompting of parents or guardians to return for additional doses, or other challenges accessing immunization providers.[17–19]

To better inform strategies for increasing early childhood vaccination coverage, we analyzed a nationally representative survey of US children. This study's objectives were to identify demographic, socioeconomic, and household factors associated with initiating all vaccine series but failing to complete multidose vaccine series. We also sought to quantify the number of remaining vaccine doses needed among US children to complete the combined 7-vaccine series.

METHODS

Data Source

Public-use National Immunization Survey-Child (NIS-Child) data collected in 2019 were analyzed. The Centers for Disease Control and Prevention administers this nationally representative telephone survey annually; the methodology has been previously described in detail.[20–23] Using 2 phases of sampling, a random-digit-dialing method was used to contact caregivers of age-eligible children, followed by a medical record review questionnaire mailed to providers to verify a child's immunization history. The study population included US children ages 19 to 35 months surveyed in 2019 with provider-verified immunization data. Detailed multistage weighting procedures, which account for sampling rate variation and nonresponse bias, are implemented so that the data collected from the survey sample can be analyzed to represent vaccination coverage at national, state, and some local levels.[21]

Outcome Measure

In this cross-sectional study, we evaluated vaccines in the combined 7-vaccine series, which includes diphtheria, tetanus, and acellular pertussis (DTaP, 4 doses), pneumococcal conjugate vaccine (PCV, 4 doses), *Haemophilus influenzae* type b (Hib, 3–4 doses depending on brand), hepatitis B (HepB, 3 doses), polio (IPV, 3 doses), measles, mumps and rubella (MMR, 1 dose), and varicella (VAR, 1 dose) vaccines.[24] The combined 7-vaccine series is the main combined measure used to evaluate early childhood vaccination coverage in the United States.[24] Although MMR and VAR are each 2-dose series, only the first dose recommended at age 12 to 15 months was considered in this study, as the second dose is not recommended until age 4 to 6 years. Other vaccinations recommended for children that are not included in the combined 7-vaccine series (rotavirus, Hepatitis A, influenza, and coronavirus disease 2019 [COVID-19] vaccines) were also not evaluated in this study.

For our outcome measure, children were classified in 1 of 3 mutually exclusive vaccination patterns: (1) completed the combined 7-vaccine series, (2) did not initiate ≥1 of the 7 vaccine series (ie, selective vaccination; this classification also included completely unvaccinated children who received 0 vaccines), or (3) initiated all series, but did not complete ≥1 multidose series (ie, missing ≥1 dose(s) from the DTaP, PCV, Hib, HepB, and IPV series). Pattern 3 was the main outcome level of interest in statistical analyses.

Statistical Analyses

Among children who did not complete the combined 7-vaccine series (Patterns 2 and 3), missing vaccine series and doses were described. Univariate frequencies and survey-weighted percentages for demographic, socioeconomic, and household factors by vaccination pattern were calculated. Rao-Scott χ-square tests were used to compare the prevalence of these factors across vaccination patterns.

Log-linked binomial regression models were used to identify demographic, socioeconomic, and household factors associated with vaccination pattern. For the primary analysis, the outcome of initiating all 7 vaccinations, but not completing ≥1 multidose series (Pattern 3) was compared with the outcome of completing the combined 7-vaccine series (Pattern 1). In secondary analyses, initiating, but not completing ≥1 multidose series (Pattern 3) was compared with not initiating ≥1 series (Pattern 2), and also Pattern 2 versus Pattern 1.[10–13,19] A priori, we determined our main exposures of interest were geographic mobility, number of vaccination providers, and breaks in insurance coverage, because these measures could be indicative of fragmented care. The NIS-Child defined geographic mobility as the child having moved across state lines since birth. Children were categorized as having 0, 1, 2, or 3 or more providers responding to the survey with vaccination data. Continuity of insurance coverage was measured as currently insured and had never been uninsured, currently insured but had been uninsured at some point since birth, currently uninsured but had been insured in the past, and currently uninsured and had never had health insurance since birth.[23] All other demographic, socioeconomic, and household characteristics measured in the survey were considered for inclusion in these models.[23] A small percentage of children had missing covariate data; these children were not included in multivariable models. We ran full models with all other covariates and tested for multicollinearity. Child's birth order was collinear with the number of children <18 years of age in the house, and insurance coverage was collinear with having a break in insurance coverage, exhibiting large variance inflation factors.[25] Therefore, the predictors of child's birth order and insurance coverage type were removed, the final models were retested for multicollinearity, and no variance inflation was observed.

Finally, we further characterized failure to complete multidose series by reporting the number and percentages of children who needed 1, 2, 3, 4, 5, 6–10, 11–13 doses, from a multidose series, to complete the combined 7-vaccine series.

The complex survey design, including clustering and stratification, was accounted for in all analyses. All percentages reported were weighted to reflect population-based estimates. Measures of association were evaluated based on effect size and 95% confidence intervals (CI) were reported. Analyses were conducted using SAS version 9.4 (Cary, NC). The University of Montana Institutional Review Board approved this secondary analysis of deidentified data under the exempt category of review.

RESULTS

Vaccine Series Completion and Vaccination Patterns

The 2019 NIS-Child survey included 16 365 US children ages 19 to 35 months with provider-verified immunization records. Completion of the combined 7-vaccine series was 72.9% (Pattern 1). For 4 out of 7 vaccines, coverage exceeded 90% (IPV: 92.3%, MMR: 91.8%, HepB: 91.3%, and VAR: 90.9%); however, 3 multidose series remained below target coverage (DTaP: 83.3%, PCV: 82.5%, Hib: 81.0%).

Approximately 1.1% of US children were completely unvaccinated for the combined 7-vaccine series (ie, received 0 vaccines). Two vaccines recommended after a child's first birthday, VAR and MMR, were the most commonly missing, with 9.1% of US children missing VAR and 8.2% missing MMR. The weighted percentages of children who had 0 doses from 1 or more of the 5 other multidose series ranged from 2.0% to 3.7%. In total, approximately 9.9% of US children had not initiated ≥1 of the 7 vaccinations (Pattern 2).

The percentages of US children who had received at least 1 vaccine dose from each vaccination in the combined 7-vaccine series but were missing ≥1 dose(s) needed to complete the multidose series were: Hib (15.5%), PCV (13.8%), DTaP (13.4%), HepB (6.6%), and IPV (4.1%).

In total, 17.2% of children initiated, but did not complete ≥1 multidose series (Pattern 3; Fig 1).

Sample Characteristics and Bivariate Associations

Among children who completed the combined 7-vaccine series (Pattern 1), fewer (8.9%) had moved across state lines since birth as compared with children who did not initiate ≥1 of the 7 vaccine series (Pattern 2, 14.6%) and children who initiated all series, but did not complete ≥1 multidose series (Pattern 3, 15.7%). Non-Hispanic white children, children whose families accessed care at private facilities, firstborn children, and children with private health insurance were more likely to have completed the combined 7-vaccine series (Pattern 1) compared with children in the other patterns. Children from low-income families, who received Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) benefits, whose mothers had lower education levels, or who lived in rented homes were more likely to have not initiated ≥1 vaccine series (Pattern 2) or to have initiated all series, but had not completed ≥1 multidose series (Pattern 3), as compared with children who completed the combined 7-vaccine series (Table 1).

Primary Analysis: Factors Associated With Failure to Complete Multidose Series

In the primary multivariable model (Pattern 3 versus Pattern 1), risk factors for initiating but not completing every multidose vaccine series included moving across state lines since birth (adjusted prevalence ratio [aPR] = 1.45; 95% confidence interval [CI]: 1.18–1.79), number of children in the household (2 or 3 children: aPR = 1.29; 95% CI: 1.05–1.58; 4 or more children: aPR = 1.68; 95% CI: 1.30–2.18), and lacking health insurance (aPR = 2.03; 95% CI: 1.42–2.91). Non-Hispanic Black children were at greater risk of not completing multidose series as compared with non-Hispanic White children (aPR = 1.28; 95% CI: 1.01–1.61). Children living in lower-income households and in rented homes

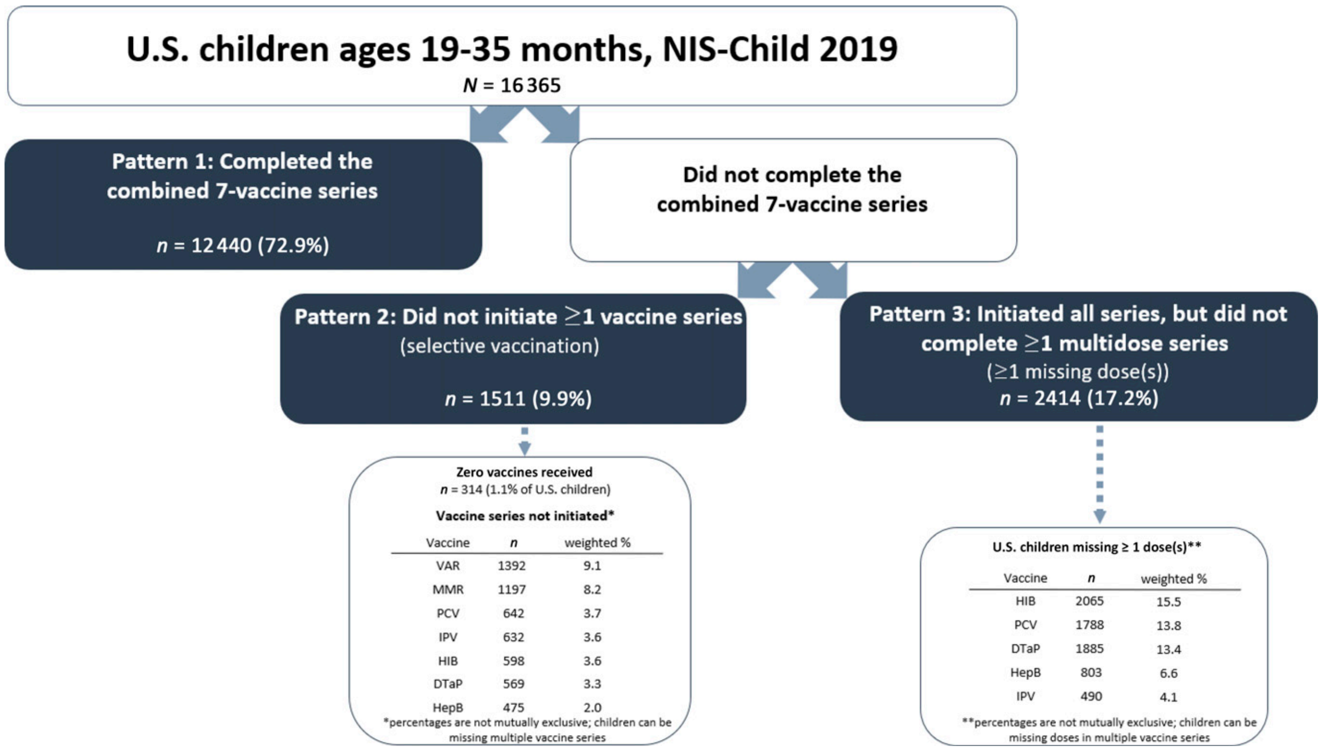

FIGURE 1
Classification of 3-level vaccination pattern outcome measure.

were 25% to 30% more likely to fail to complete multidose vaccine series (Table 2).

Secondary Analyses

In the secondary analysis examining only children who did not complete the combined 7-vaccine series (Pattern 3 versus Pattern 2), having multiple immunization providers increased in the risk of starting but failing to complete all series by approximately 50% (aPR = 1.48, 95% CI: 1.17–1.87; Supplemental Table 4). In the other secondary analysis, moving across state lines, living in a rented home, and being uninsured were associated with not initiating ≥1 vaccination(s) (Pattern 2), as compared with children who completed the combined 7-vaccine series (Pattern 1), which were similar to some findings from the primary analysis. Unique predictors for not initiating ≥1 vaccination(s) (Pattern 2) included lower maternal education level (aPR = 1.50, 95% CI: 1.07–2.11) and more vaccine providers (2 providers: aPR = 0.55, 95% CI: 0.35–0.86; 3 or more providers: aPR = 0.22, 95% CI: 0.08–0.57; Supplemental Table 5).

Remaining Doses Needed to Complete Multidose Vaccine Series

Among children who had not completed the combined 7-vaccine series solely because of missing doses from multidose vaccine series (Pattern 3), 47.2% needed only 1 remaining dose to complete the combined 7-vaccine series. Approximately, 22.2% and 15.0% of these children needed 2 or 3 doses, respectively. Few children in this pattern (15.6%) needed 4 or more doses to complete the combined 7-vaccine series (Table 3). Applied to the entire study population, 8.4% of US children needed only 1 additional dose from a multidose vaccine series to have completed the combined 7-vaccine series, and an additional 10.5% needed 2 to 5 doses.

DISCUSSION

In this analysis of nationally-representative NIS-Child data, we found that moving across state lines, higher numbers of children in the household, lacking health insurance, lower household income, living in a rented home, and race and ethnicity were each associated with a 20% or greater risk of failure to complete multidose vaccine series in early childhood. A noteworthy proportion of US children (8.4%) needed only 1 additional vaccine dose from 1 of the 5 multidose series to complete the combined 7-vaccine series. If children who were missing only 1 outstanding dose from a multidose vaccine series had received that final dose, the United States would have achieved the Healthy People 2020 goal of 80% coverage for combined 7-vaccine series completion in 2019.[26]

TABLE 1 Characteristics of Study Population and Bivariate Associations Between Demographic, Socioeconomic, and Household Factors and Vaccination Pattern at the Time of Household Interview, US Children Ages 19 to 35 mo, NIS-Child 2019					
		Vaccination Pattern			
Characteristics	**Total Study Sample, N = 16 365, n (weighted %)**	**Pattern 1: Completed the Combined 7-Vaccine Series, n = 12 440 (72.9%), n (weighted column %)**	**Pattern 2: Did Not Initiate ≥ 1 Vaccine Series, n = 1511 (9.9%), n (weighted column %)**	**Pattern 3: Initiated All Series, but Did Not Complete ≥1 Multidose Series, n = 2414 (17.2%), n (weighted column %)**	**P[a]**
Child's sex					.53
Female	7776 (48.8)	5932 (48.8)	722 (51.7)	1122 (47.5)	
Male	8589 (51.2)	6508 (51.2)	789 (48.3)	1292 (52.5)	
Race and ethnicity					.002
White alone, non-Hispanic	9803 (47.2)	7656 (49.2)	853 (43.0)	1294 (40.7)	
Black alone, non-Hispanic	1144 (12.7)	796 (11.5)	140 (14.0)	208 (16.9)	
All other races alone and multiple races, non-Hispanic	2107 (12.9)	1547 (13.0)	224 (14.2)	336 (11.7)	
Any race, Hispanic	3311 (27.3)	2441 (26.2)	294 (28.8)	576 (30.8)	
Child's age at time of survey interview					.008
19–23 mo	5068 (30.0)	3682 (28.2)	526 (35.7)	860 (34.5)	
24–29 mo	5052 (33.6)	3892 (34.7)	449 (32.5)	711 (29.7)	
30–35 mo	6245 (36.3)	4866 (37.1)	536 (31.7)	843 (35.8)	
Census region					.15
Northeast	2748 (15.8)	2165 (16.2)	236 (15.5)	347 (14.4)	
South	6563 (39.3)	4989 (39.2)	579 (35.3)	995 (41.7)	
West	3657 (24.1)	2667 (23.1)	404 (27.6)	596 (26.4)	
Midwest	3397 (20.8)	2619 (21.4)	292 (21.7)	486 (17.5)	
Geographic mobility					<.001
Has moved across state lines since birth	1771 (10.7)	1133 (8.9)	264 (14.6)	374 (15.7)	
Has not moved across state lines since birth	14 594 (89.3)	11 307 (91.1)	1247 (85.4)	2040 (84.3)	
Vaccine provider facility type					<.001
All private facilities	8736 (56.6)	7026 (59.7)	523 (45.0)	1187 (49.6)	
All public facilities	1740 (12.4)	1195 (11.0)	169 (15.6)	376 (17.0)	
All hospital facilities	2796 (14.5)	2097 (13.6)	318 (22.9)	381 (13.9)	
All military or other facilities	435 (3.2)	313 (2.9)	53 (4.1)	69 (3.8)	
Mixed facility types	2371 (13.3)	1809 (12.9)	161 (12.4)	401 (15.7)	
Number of vaccine providers[b]					<.001
1	13 290 (84.8)	10 214 (84.0)	1079 (90.9)	1997 (85.0)	
2	2506 (13.7)	2003 (14.5)	136 (8.8)	367 (12.8)	
3 or more	282 (1.5)	223 (1.5)	9 (0.4)	50 (2.2)	
Maternal education					<.001
<12 y	1398 (14.2)	920 (12.0)	181 (20.1)	297 (20.3)	
12 y	2552 (24.8)	1778 (23.6)	294 (27.7)	480 (28.1)	
>12 y	4204 (22.0)	3070 (21.7)	456 (25.8)	678 (20.8)	
College graduate	8211 (39.1)	6672 (42.8)	580 (26.4)	959 (30.7)	

TABLE 1 Continued

Characteristics	Total Study Sample, $N = 16\,365$, *n* (weighted %)	Vaccination Pattern: Pattern 1: Completed the Combined 7-Vaccine Series, $n = 12\,440$ (72.9%), *n* (weighted column %)	Pattern 2: Did Not Initiate ≥ 1 Vaccine Series, $n = 1511$ (9.9%), *n* (weighted column %)	Pattern 3: Initiated All Series, but Did Not Complete ≥1 Multidose Series, $n = 2414$ (17.2%), *n* (weighted column %)	*P*[a]
Child ever received WIC benefits					<.001
Yes	6297 (48.8)	4519 (46.1)	633 (54.5)	1145 (57.3)	
Not yes[c]	10 068 (51.2)	7921 (53.9)	878 (45.5)	1269 (42.7)	
Child's birth order					<.001
Firstborn	6327 (37.0)	5069 (39.5)	485 (31.7)	773 (29.6)	
Not firstborn	10 038 (63.0)	7371 (60.5)	1026 (68.3)	1641 (70.4)	
Number of children <18 y of age in the house					<.001
1	4490 (27.4)	3589 (28.8)	330 (25.0)	571 (22.4)	
2 or 3	9828 (57.4)	7533 (58.4)	862 (51.8)	1433 (56.3)	
4 or more	2047 (15.2)	1314 (12.7)	319 (23.2)	410 (21.3)	
Home ownership					<.001
Home was owned or being bought	10 216 (53.2)	8141 (57.4)	798 (42.7)	1277 (41.3)	
Home was rented	5541 (42.8)	3876 (38.8)	630 (53.2)	1035 (53.8)	
Other arrangement	565 (4.0)	393 (3.8)	72 (4.1)	100 (4.9)	
Poverty status					<.001
Above poverty, ≥$75 000	7668 (40.6)	6254 (44.5)	518 (30.2)	896 (29.5)	
Above poverty, ≤$75 000	5044 (32.5)	3707 (31.6)	545 (34.7)	792 (35.2)	
Below poverty	3124 (26.9)	2128 (23.9)	370 (35.1)	626 (35.4)	
Insurance coverage					<.001
Private insurance only	8803 (44.4)	7165 (48.4)	605 (34.8)	1033 (32.9)	
Any Medicaid insurance	5706 (44.6)	4009 (41.8)	648 (50.4)	1049 (52.8)	
Other insurance[d]	1356 (7.7)	988 (7.5)	146 (8.3)	222 (8.3)	
Uninsured at any time of survey	500 (3.3)	278 (2.3)	112 (6.5)	110 (6.0)	
Break in insurance coverage					<.001
Currently insured and has never had a break	14 744 (89.4)	11 396 (90.8)	1258 (84.4)	2090 (85.8)	
Currently insured but had a break at some point	1093 (7.4)	754 (6.9)	134 (9.2)	205 (8.5)	
Currently uninsured but has had insurance in the past	349 (2.3)	214 (1.8)	54 (3.0)	81 (4.0)	
Currently uninsured and has never had insurance	144 (0.9)	61 (0.4)	56 (3.4)	27 (1.7)	

CHIP, Children's Health Insurance Program; NIS, National Immunization Survey; IHS, Indian Health Service; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.
[a] *P* values were calculated using Rao-Scott χ-square tests to account for complex survey design.
[b] Children with 0 providers ($n = 287$) were excluded from this Rao-Scott χ-square test as all 287 children, by definition, had not started any vaccine series.
[c] Not yes represents no, do not know, never heard of WIC, and refused to answer responses.
[d] Other insurance may include: CHIP, IHS, military, or other, alone or in combination with private insurance.

By comprehensively describing US children who failed to complete multidose vaccine series, this study adds to a limited body of recently published research that we identified on non-hesitancy-related immunization services challenges. Although prior surveys of parents have found that not starting vaccine series at all (ie, "selective vaccination"[10–12]) is largely indicative of parental hesitancy, there have not been strong links observed between parental hesitancy and starting all recommended vaccinations but failing to complete multidose vaccine series.[13,27] In contrast to addressing parental

TABLE 2 Factors Associated With Initiating All Series, but Not Completing Multidose Vaccine Series, US Children Ages 19 to 35 mo		
	Pattern 3: Initiated All Series, but Did Not Complete ≥1 Multidose Series, *n* = 2414 (17.2%) Versus Pattern 1: Completed the Combined 7-Vaccine Series, *n* = 12 440 (72.9%)	
Characteristics	**Prevalence Ratio (95% CI), Unadjusted**	**Prevalence Ratio (95% CI), Adjusted[a]**
Race and ethnicity		
White alone, non-Hispanic	Referent	Referent
Black alone, non-Hispanic	1.58 (1.29–1.94)	1.28 (1.01–1.61)
All other races alone and multiple races, non-Hispanic	1.07 (0.87–1.31)	0.91 (0.73–1.14)
Any race, Hispanic	1.33 (1.08–1.64)	0.92 (0.74–1.16)
Child's age at time of survey interview		
19–23 mo	1.21 (1.00–1.46)	1.22 (1.01–1.47)
24–29 mo	0.91 (0.75–1.10)	0.90 (0.74–1.10)
30–35 mo	Referent	Referent
Census region		
Northeast	0.86 (0.72–1.04)	0.95 (0.78–1.15)
South	Referent	Referent
West	1.06 (0.83–1.35)	1.15 (0.90–1.45)
Midwest	0.81 (0.69–0.94)	0.84 (0.71–0.99)
Geographic mobility		
Has moved across state lines since birth	1.64 (1.35–1.98)	1.45 (1.18–1.79)
Has not moved across state lines since birth	Referent	Referent
Vaccine provider facility type		
All private facilities	Referent	Referent
All public facilities	1.64 (1.32–2.04)	1.23 (0.97–1.56)
All hospital facilities	1.19 (0.93–1.52)	1.18 (0.91–1.51)
All military or other facilities	1.46 (0.91–2.33)	1.20 (0.74–1.93)
Mixed facility types	1.37 (1.10–1.69)	1.24 (0.99–1.55)
Number of vaccine providers		
1	Referent	Referent
2	0.90 (0.72–1.12)	0.89 (0.72–1.10)
3 or more	1.33 (0.90–1.98)	1.09 (0.72–1.65)
Maternal education		
<12 y	1.98 (1.54–2.53)	1.31 (0.95–1.81)
12 y	1.52 (1.23–1.86)	1.15 (0.92–1.44)
>12 y	1.27 (1.05–1.55)	1.02 (0.83–1.27)
College graduate	Referent	Referent
Child ever received WIC benefits		
Yes	1.44 (1.23–1.69)	0.88 (0.70–1.12)
Not yes[b]	Referent	Referent
Child's birth order[c]		
Firstborn	0.70 (0.59–0.83)	NA
Not firstborn	Referent	NA
Number of children <18 y of age in the house		
1	Referent	Referent
2 or 3	1.20 (0.98–1.46)	1.29 (1.05–1.58)
4 or more	1.83 (1.44–2.33)	1.68 (1.30–2.18)
Home ownership		
Home was owned or being bought	Referent	Referent
Home was rented	1.70 (1.45–1.99)	1.29 (1.04–1.59)
Other arrangement	1.61 (1.19–2.19)	1.27 (0.90–1.80)
Poverty status		
Above poverty, ≥$75 000	Referent	Referent
Above poverty, ≤$75 000	1.55 (1.27–1.88)	1.32 (1.01–1.73)
Below poverty	1.92 (1.56–2.37)	1.35 (0.97–1.87)

TABLE 2 Continued

Characteristics	Pattern 3: Initiated All Series, but Did Not Complete ≥1 Multidose Series, n = 2414 (17.2%) Versus Pattern 1: Completed the Combined 7-Vaccine Series, n = 12 440 (72.9%)	
	Prevalence Ratio (95% CI), Unadjusted	Prevalence Ratio (95% CI), Adjusted[a]
Insurance coverage[c]		
Private insurance only	Referent	NA
Any Medicaid insurance	1.66 (1.40–1.98)	NA
Other insurance[d]	1.51 (1.19–1.91)	NA
Uninsured at any time	2.76 (2.11–3.60)	NA
Break in insurance coverage		
Currently insured and has never had a break	Referent	Referent
Currently insured but had a break at some point	1.24 (0.97–1.59)	1.06 (0.83–1.36)
Currently uninsured but has had insurance in the past	1.85 (1.36–2.50)	1.46 (1.05–2.03)
Currently uninsured and has never had insurance	2.68 (1.86–3.86)	2.03 (1.42–2.91)

CI, confidence interval; CHIP, Children's Health Insurance Plan; IHS, Indian Health Service; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children; NA, not applicable.
[a] Missing data were excluded from adjusted model. A total of n = 14 356 observations were used. Poverty status had n = 529 children missing data, n = 287 children had 0 vaccine providers and thus were also missing data on vaccine provider facility type, n = 43 children were missing data on home ownership, and n = 35 children were missing data on breaks in insurance coverage.
[b] Not yes represents no, do not know, never heard of WIC, and refused to answer responses.
[c] Because of collinearity between birth order and number of children <18 y of age in the house as well as insurance coverage and breaks in insurance coverage, birth order and insurance coverage were excluded from the multivariable model.
[d] Other insurance may include: CHIP, IHS, military, or other, alone or in combination with private insurance.

hesitancy, for which effective interventions are limited, the deficits caused by failing to complete multidose vaccine series have actionable and established health systems and provider-level solutions. Examples include more widespread adoption of reminder-recall systems,[28,29] expanding immunization services delivery to outside of primary care settings[30] and with greater flexibility in scheduling,[31] automated electronic health record prompts at the point of care,[28] and previsit planning to avoid missed opportunities to vaccinate.[32–34]

Our findings regarding lower household income and lack of insurance as risk factors for failing to complete multidose vaccine series indicate that despite gains in vaccination coverage and reductions in disparities achieved because of the federal Vaccines for Children program, gaps still remain.[35–37] Along with facilitating linkages with the Vaccines for Children program, there is also an opportunity for clinics to help coordinate insurance enrollment for eligible uninsured children who likely have other unmet medical care needs, in addition to undervaccination.[38–40] Moreover, our finding that non-Hispanic Black children were less likely to have completed multidose vaccine series signals that reduced access to high quality health care services among racial and ethnic minorities is evident in immunization outcomes.[41,42] Pediatric health equity cannot be achieved without increasing support for low-income children and children from racial minority groups, who, as most recently highlighted by the COVID-19 pandemic, are most at-risk for infectious diseases and poorer outcomes because of social and environmental determinants of health.[43,44]

Multiple explanations exist for why moving across state lines was identified as a risk factor for failing to complete multidose vaccine series. Parents or guardians may have faced challenges establishing a new medical home after moving, particularly for children insured by Medicaid or with lapses in insurance coverage.[45–48] Alternatively, children may have received all recommended vaccines, but record scatter caused them to appear to be missing final doses from multidose series. Regardless, if a child is actually missing a vaccine dose or if documentation of the vaccine dose is lacking, the clinical implications are the same. Guidelines advise that vaccine doses should be repeated if vaccination status is unknown or uncertain.[18,49] Innovative approaches such as deploying immunization coordinators from state and local health departments[50] as well as efforts to expand cross-state immunization information system (IIS) communication,[51]

TABLE 3 Remaining Doses From Multidose Vaccine Series Needed to Complete the Combined 7-Vaccine Series, US Children Ages 19 to 35 mo

Number of Remaining Doses From Multidose Vaccine Series Needed to Complete the Combined 7-Vaccine Series	Pattern 3: Initiated All Series, but Did Not Complete ≥1 Multidose Series, n = 2414, n (weighted column %)
1 dose	1213 (47.2)
2 doses	508 (22.2)
3 doses	359 (15.0)
4 doses	125 (4.8)
5 doses	53 (2.8)
6–10 doses	130 (5.3)
11–13 doses	26 (2.7)

are strategies that can support both timely multidose series completion and continuity in immunization history tracking.

Although there have been several recent studies examining trends in and factors associated with not initiating vaccinations (ie, "selective vaccination"[10–13], Pattern 2), this current study fills a gap in current research on factors associated with undervaccination due only to missing doses in multidose vaccine series. Of note, we observed similar findings with regard to associations between moving across state lines, living in a rented home, and lack of insurance as risk factors in both our primary analysis of failing to complete multidose series (Pattern 3), and in our secondary analysis of not initiating ≥1 vaccination in the combined 7-vaccine series (ie, selective vaccination, Pattern 2). The majority of children in Pattern 2 were missing MMR or varicella vaccinations, for which 1 dose is recommended at ages 12 to 15 months. Although MMR and varicella are among the most commonly refused vaccinations by parents,[52,53] our results suggest structural barriers to accessing timely immunization services may be contributing to both failure to complete multidose series and lack of receipt of MMR and varicella after the first birthday.

This study had several limitations. First, although we studied risk factors for series noncompletion, we did not have information on the specific reason why children were missing vaccine doses. Some children may have been missing doses because of a contraindication or an adverse event following a prior dose, though serious adverse events with a clinical indication to not complete a series are rare.[54–56] It is also possible that some of the lack of multidose series completion could been because of parental hesitancy. Second, missing data are inherent in survey design, and some providers may not have a child's complete immunization history, which could have resulted in outcome misclassification because of missing records. Also, a small percentage of responses were removed from multivariable analyses because of missing covariate data. A third limitation was that previous work has documented children whose parents chose to participate in NIS-Child have higher vaccination coverage than children whose parents decline participation.[22] Although NIS-Child integrates complex survey weighting to account for survey nonresponse bias, it is possible that vaccination coverage could still be slightly overestimated in the data source and the prevalence of missing doses and series noncompletion was therefore underestimated.[23] Finally, a limitation of the NIS-Child data source is that other factors likely associated with series completion are not measured in the survey, such as geographic distance to providers and availability of transportation. Moreover, facilitators of multidose vaccine series completion, such as reminder-recall systems, clinical decision support tools, and flexible appointment availability are not measured in the survey. These clinic-level facilitators should be utilized in efforts targeting multidose series completion.

CONCLUSIONS

Optimizing timely multidose series completion in the first 2 years of life is necessary for disease protection and durable immunity for individuals as well as to develop and maintain herd immunity at a population level. Our findings regarding socioeconomic and racial and ethnic disparities indicate that established strategies for facilitating multidose series completion, such as reminder-recall, are not reaching all communities. Renewed efforts to better support timely completion of multidose vaccine series in early childhood are needed to achieve vaccination coverage goals.

ABBREVIATIONS

CHIP: Children's Health Insurance Plan
CI: confidence interval
DTaP: diphtheria, tetanus, acellular pertussis vaccine
HepB: hepatitis B vaccine
Hib: *Haemophilus influenzae* type b vaccine
IHS: Indian Health Service
IIS: Immunization Information System
IPV: inactivated poliovirus vaccine
MMR: measles, mumps, and rubella vaccine
NIS: National Immunization Survey
PCV: pneumococcal conjugate vaccine
VAR: varicella vaccine
WIC: Special Supplemental Nutrition Program for Women, Infants, and Children

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