Vaccine Administration in Children's Hospitals

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abstract

OBJECTIVES: To examine inpatient vaccine delivery across a national sample of children's hospitals.

METHODS: We conducted a retrospective cohort study examining vaccine administration at 49 children's hospitals in the Pediatric Health Information System database. Children <18 years old admitted between July 1, 2017, and June 30, 2019, and age eligible for vaccinations were included. We determined the proportion of hospitalizations with ≥1 dose of any vaccine type administered overall and by hospital, the type of vaccines administered, and the demographic characteristics of children who received vaccines. We calculated adjusted hospital-level rates for each vaccine type by hospital. We used logistic and linear regression models to examine characteristics associated with vaccine administration.

RESULTS: There were 1 185 667 children and 1 536 340 hospitalizations included. The mean age was 5.5 years; 18% were non-Hispanic Black, and 55% had public insurance. There were ≥1 vaccine doses administered in 12.9% (95% confidence interval: 12.8–12.9) of hospitalizations, ranging from 1% to 45% across hospitals. The most common vaccines administered were hepatitis B and influenza. Vaccine doses other than the hepatitis B birth dose and influenza were administered in 1.9% of hospitalizations. Children had higher odds of receiving a vaccine dose other than the hepatitis B birth dose or influenza if they were <2 months old, had public insurance, were non-Hispanic Black race, were medically complex, or had a length of stay ≥3 days.

CONCLUSIONS: In this national study, few hospitalizations involved vaccine administration with substantial variability across US children's hospitals. Efforts to standardize inpatient vaccine administration may represent an opportunity to increase childhood vaccine coverage.

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WHAT'S KNOWN ON THIS SUBJECT: Hospitalized children are often missing recommended vaccines, with previous single-center studies revealing between 27% to 84% of hospitalized children are missing ≥1 vaccine. There are limited data describing vaccine administration in US children's hospitals.

WHAT THIS STUDY ADDS: In this retrospective study that included 2017–2019 administrative data from 49 children's hospitals, ≥1 vaccine doses were administered during 12.9% of 1 536 340 hospitalizations. The proportion of hospitalizations where ≥1 vaccine doses were administered varied by hospital from 1% to 45%.

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Childhood vaccines are one of the most effective public health interventions to prevent childhood morbidity and mortality worldwide.[1,2] Despite this, many children remain undervaccinated, with vaccination rates currently below the US Department of Health and Human Services *Healthy People 2030* goals.[3,4] These children are at higher risk of developing vaccine-preventable diseases[5–8] and have higher all-cause hospital admission compared with children who are fully vaccinated.[9]

Single-center studies of undervaccination in hospitalized children reveal that 27% to 84% of children are missing recommended vaccines.[10–14] A majority of hospitalized children need only 1 to 2 vaccines to be considered up to date (UTD).[11,12,14–17] The Advisory Committee on Immunization Practices (ACIP) recommends vaccinating hospitalized children and improving efforts to ensure vaccine administration during hospitalization.[18] In the era of population-based Immunization Information Systems (IISs) in which individual vaccine records are accessible to hospital-based providers, hospitalization has been increasingly recognized as an opportunity to provide vaccinations for children who are not UTD.[11,13,19–21]

Hospitals have had success providing vaccinations to hospitalized children.[11,12,14,15,19,21–25] However, many of these efforts have specifically focused on influenza vaccines[19,21,23–25] and the birth dose of the hepatitis B vaccine.[26,27] Few studies of hospital-based vaccinations have examined baseline vaccine administration rates before implementing interventions to provide vaccines, particularly for routine childhood vaccines other than influenza and the hepatitis B birth dose.[10,16,17,28] Importantly, in studies that examined baseline rates, investigators estimate that <20% of hospitalized children received any needed vaccines.[10,16,17,28] Furthermore, previous studies have been primarily limited to single-center studies.[10,11,13,19–21] Currently, there is a gap in our understanding of vaccine administration during hospitalization across different hospitals.[29]

The primary aim with this study was to examine inpatient vaccine delivery across a national sample of children's hospitals. The specific objectives were to (1) identify the types of vaccines administered to hospitalized children, (2) examine variation in vaccine administration across children's hospitals nationally, and (3) describe the demographic and clinical characteristics of children who received any routine childhood vaccinations during hospitalization, excluding influenza and the birth dose of hepatitis B vaccine.

METHODS

We conducted a retrospective cohort study of vaccine administration in children's hospitals using the Pediatric Health Information System (PHIS) database. PHIS is an administrative billing database administered by the Children's Hospital Association (Lenexa, KS) that includes pharmacy data for inpatient encounters for 49 US children's hospitals. Hospitalizations for children <18 years old admitted to a PHIS hospital between July 1, 2017, and June 30, 2019, were included. We included all children <18 years as routine and catch-up vaccinations are relevant to all ages.[30] We excluded children who had a condition that would alter the recommended vaccination schedule according to ACIP guidelines by using the *International Statistical Classification of Diseases and Related Health Problems, 10th Revision* (ICD-10) codes for diagnoses and Pharmaceutical Clinical Transaction Classification (CTC) codes for medications, such as chemotherapeutic drugs (Supplemental Table 5). Children who died during hospitalization or were discharged to hospice care were excluded. This study was categorized as not human subjects research by the Institutional Review Board at Seattle Children's Hospital.

Outcomes

Our primary outcome was administration of ≥1 dose of any vaccine type to children who were age eligible during an inpatient hospitalization in the study period. Our secondary outcome was administration of ≥1 dose of any recommended childhood vaccine other than influenza and the hepatitis B birth dose, described as routine childhood vaccines for the remainder of this article.

Vaccine administration data were obtained from the PHIS database by using CTC codes for the following vaccines: diphtheria, tetanus, acellular pertussis (DTaP/Tdap); hepatitis B; rotavirus; *Haemophilus influenza*e type B; pneumococcal conjugate; inactivated poliovirus (IPV); measles, mumps, rubella (MMR); varicella; hepatitis A; meningococcal; human papillomavirus (HPV); and influenza. Hepatitis B vaccine doses were dichotomized into birth dose (if administered at <31 days of age) and nonbirth dose (if administered at ≥31 days of age).

Children were considered age eligible for a vaccine dose if their admit or discharge age was within the recommended age window for receiving a childhood vaccine dose according to the routine and catch-up vaccination schedules from the Centers for Disease Control and Prevention (CDC) (Table 1).[30]

TABLE 1 Summary Statistics of the Number of Children Who Were Administered Any Vaccines During a Single Hospitalization

Types of Vaccines	Hospital Visits Where the Child Was Administered ≥1 Vaccine, n = 198 076	Population (No. Hospitalizations of Age Appropriate Children),[b] n = 1 536 340	Rate of Vaccine Administration Per 1000 Hospitalizations
Influenza[a]	48 716	795 198	61
Hepatitis B total	142 861	1 536 340	93
Birth dose	126 691	254 108	499
Nonbirth dose	16 170	1 282 232	13
H influenzae type B	15 913	602 668	26
Pneumococcal conjugate vaccine	19 323	602 668	32
DTaP	17 509	708 766	25
IPV	15 721	1 288 110	12
Rotavirus	2790	177 883	16
MMR	1186	1 051 557	1
Varicella	1116	1 051 557	1
Hepatitis A	1666	1 051 557	2
TdaP	3514	579 937	6
Meningococcal	1578	395 706	4
HPV	468	488 296	1

[a] For influenza vaccinations, in addition to age eligibility, children had to be admitted or discharged during influenza season (September 1 through April 30).
[b] Age ranges per the CDC Recommended Vaccine Schedule[1]: Influenza ≥6 mo; hepatitis B ≥0 mo; *H influenzae* type B ≥6 wk and <5 y; pneumococcal conjugate vaccine ≥6 wk and <5 y; DTaP ≥6 wk and <7 y; IPV: ≥6 wk; rotavirus ≥6 wk and <8 mo; MMR, varicella, hepatitis A: ≥1 y; Tdap ≥7 y; meningococcal ≥11 y; HPV ≥9 y.

Children were considered eligible for influenza vaccine doses if their admission date or discharge date was during influenza season (September through April).

Patient Characteristics

Demographic variables including age, race, ethnicity, and insurance status were obtained from PHIS. Medical complexity was assessed by using the Pediatric Medical Complexity Algorithm (PMCA).[31] Age was examined as a continuous variable and categorized on the basis of age categories used by the CDC to estimate population-level vaccine coverage (0–18 months, 19–35 months, 3–6 years, 7–12 years, and ≥13 years).[32]

Hospitalization Characteristics

We obtained length of stay (LOS), ICU status, and season of admission for each hospitalization from PHIS. We examined mean LOS in days and also assessed LOS categorically (<3 days, 3–7 days, 7–30 days, and >30 days). Season of admission was categorized as influenza season (September through April) or noninfluenza season (May through August). We included these variables because we hypothesized that they may be related to vaccine administration during hospitalization; for example, children with longer LOS may be administered more vaccine doses.

Statistical Analysis

We used descriptive statistics to assess (1) the number and proportion of each type of vaccine administered during hospitalization and (2) the number and proportion of hospitalizations where children were administered ≥1 vaccine dose of any type for which they were age eligible. To describe variation by vaccine type and hospital, we first calculated unadjusted proportions with 95% confidence intervals (CIs) of age-eligible hospitalizations in which ≥1 dose was administered for each vaccine for each hospital. We risk adjusted hospital-level rates of vaccine doses administered per 1000 hospitalizations by including hospital-level covariates in a generalized linear mixed-effects regression model. Covariates in the model were age, sex, race and ethnicity, insurance, PMCA, and LOS with hospital as a fixed effect. Because population-based rates of vaccination vary nationally, we adjusted the model to account for population-level rates by age based on the CDC's population-level estimates (Supplemental Table 6).[32] To model the relationship between administration of doses of different vaccines at the hospital level, risk-adjusted vaccine administration rates were divided into quintiles on the basis of the percent difference from the risk-adjusted median rate of vaccine administration per 1000 hospitalizations by vaccine type. Given the number of hospitals and vaccines included in this study, a heat map was developed to display the risk-adjusted median rates of vaccine administration in quintiles.[33,34] Quintiles were created to classify hospitals with risk-adjusted median rates at (1) >25% below the median, (2) 10% to 25% below the median, (3) <10% above or below the median, (4) 10% to 25% above the median, and (5) >25% above the median.

Lastly, we used descriptive statistics to examine demographic, clinical and hospital visit characteristics of children who received ≥1 vaccine dose of any routine childhood vaccine (excluding influenza and hepatitis B birth dose). We examined the relationship between

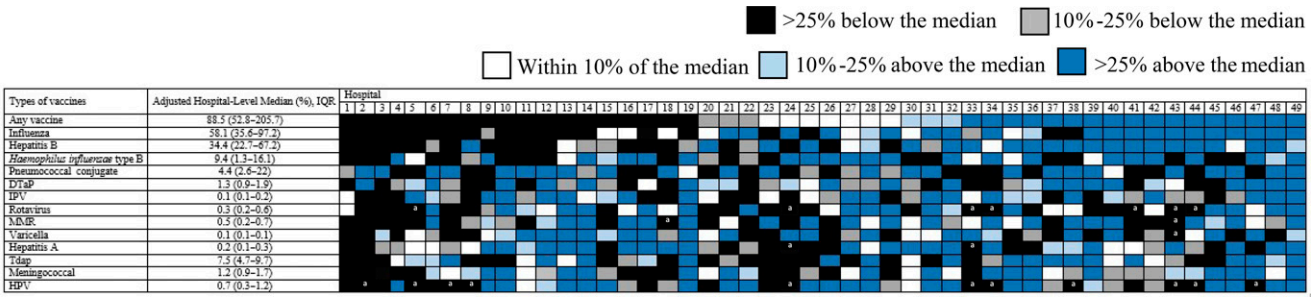

FIGURE 1

Adjusted hospital-level median rate of vaccinations per 1000 hospitalizations by vaccine type. Rates were adjusted at the hospital level for age, sex, insurance type, level of medical complexity, race and ethnicity, LOS, and state vaccination rates. DTaP, vaccine for age <7 years. Tdap: vaccine for age ≥7 years. [a] Indicates 0 vaccines of that type were given.

receipt of any routine childhood vaccine excluding influenza and hepatitis B birth dose and demographic, clinical, and hospital visit characteristics using linear regression models for continuous variables and logistic regression models for categorical variables.

Sensitivity Analysis

We conducted a sensitivity analysis excluding hospitalizations of children who were admitted at <2 months of age. We hypothesized that there may be differences in vaccine administration for these children because they were only age eligible for hepatitis B vaccines at the time of admission. Furthermore, this population includes many children who were admitted to the NICU. Children in the NICU are at risk for undervaccination, and there may be hospital-level policies related to vaccinations for this population.[26,35–39] We examined the demographic, clinical, and hospital visit characteristics associated with administration of ≥1 noninfluenza, nonbirth dose hepatitis B vaccine dose in children ≥2 months of age at the time of hospitalization.

RESULTS

There were 1 536 340 hospitalizations involving 1 185 667 children who met inclusion criteria during the study period. The mean age was 5.5 years (SD 5.8 years); 46% were female, 43% were White, 18% were non-Hispanic Black, and 55% had public insurance. The mean hospital LOS was 4.8 days (SD 13.9). Twelve percent of children were admitted to the ICU; 70% were admitted during influenza season (September through April) (Table 2).

There was ≥1 vaccine dose administered in 198 076 of the 1 536 340 hospitalizations included in this study (12.9%; 95% CI: 12.8–12.9). A total of 272 361 vaccine doses were administered. The proportion of hospitalizations where ≥1 vaccine dose was administered varied by hospital from 1% to 45% (Fig 1, Supplemental Tables 7 and 8). The most common types of vaccines administered were hepatitis B (n =142 861; 9.3% [95% CI: 9.25%–9.34%] of hospitalizations with age-eligible children) and influenza (n = 48 716; 6.1% [95% CI: 6.07%–6.18%] of age-eligible children admitted during influenza season) (Table 2). Eighty-eight percent of hepatitis B vaccine doses were given to children age <31 days. In 1.9% (95% CI: 1.86%–1.90%, n = 28 912) of hospitalizations, a child was administered ≥1 vaccine doses other than influenza vaccine or birth dose of hepatitis B vaccine, most commonly pneumococcal conjugate, *H influenza*e type B, or DTaP (Table 1).

Overall, the adjusted hospital-level median rate of vaccine administration was 88.5 per 1000 hospitalizations (25% to 75% interquartile range [IQR]: 52.8–205.7). The adjusted hospital-level median rate of vaccine doses administered per 1000 hospitalizations varied by vaccine and by hospital (Fig 1). The most common vaccine doses administered were the birth dose hepatitis B vaccine (adjusted median rate: 193.9 [IQR: 133.3–496.9]) and influenza vaccine (adjusted median rate: 58.1 [IQR: 35.6–97.2]) (Fig 1, Supplemental Tables 7 and 8). There were a number of hospitals that delivered no vaccine doses for certain vaccine types: rotavirus (n = 7 hospitals), MMR (n = 2), varicella (n = 1), hepatitis A (n = 2), and HPV (n = 11) (Fig 1, Supplemental Tables 7 and 8).

Compared with children age 3 to 6 years, children who were admitted at age <2 months had the highest odds of being administered ≥1 dose of a routine childhood vaccine, excluding influenza and the hepatitis B vaccine birth dose (n = 14 061, odds ratio: 8.9; 95% CI: 8.4–9.4). All age groups had higher odds of being administered any routine childhood

TABLE 2 Study Population

	Population, $N = 1\,536\,340$
Admit age, *n* (%)	
<2 mo	296 399 (19)
2–18 mo	279 858 (18)
19–35 mo	142 808 (9)
3–6 y	237 931 (15)
7–12 y	283 888 (18)
≥13 y	295 456 (19)
Age mean (SD)	5.5 (5.8)
Sex, female, *n* (%)	710 430 (46)
Race and ethnicity, *n* (%)	
Non-Hispanic White	667 718 (43)
Non-Hispanic Black	277 816 (18)
Hispanic	306 547 (20)
Other	139 162 (9)
Missing	145 097 (9)
Insurance, *n* (%)	
Private	671 722 (44)
Public	840 736 (55)
Missing	23 882 (2)
PMCA, *n* (%)	
No chronic disease	632 299 (41)
Noncomplex chronic	378 544 (25)
Complex chronic	525 497 (34)
ICU stay (yes), *n* (%)	188 031 (12)
Influenza season, *n* (%)	
May to August	467 177 (30)
September to April	1 069 163 (70)
Hospital LOS, mean LOS (SD)	4.8 (13.9)
Categorical LOS, *n* (%), d	
<3	959 436 (62)
3–7	403 106 (26)
8–30	139 688 (9)
>30	34 110 (2)

vaccine during hospitalization compared with children age 3 to 6 years (Table 3). Children who were identified as non-Hispanic Black and other race had higher odds of receiving routine childhood vaccines during hospitalization compared with children who were non-Hispanic White race and Hispanic ethnicity. Children with public insurance had higher odds of receiving ≥1 routine childhood vaccine during hospitalization compared with children with private insurance (odds ratio: 1.4; 95% CI 1.4–1.4) (Table 3). Children with higher levels of medical complexity (noncomplex chronic and complex chronic) had higher odds of receiving ≥1 routine childhood vaccine compared with children with no chronic disease. Children who had a longer LOS had higher odds of receiving any routine childhood vaccines compared with children who had a LOS of <3 days.

When we excluded children who were admitted at <2 months of age ($n = 14\,061$), we identified similar associations between vaccine administration and age, race, ethnicity, insurance status, ICU admission, and LOS as the primary analysis of children age ≥2 months ($n = 14\,851$) (Table 4).

DISCUSSION

In this retrospective cohort study, we examined vaccine administration during hospitalization using a national sample of US children's hospitals. We identified that vaccine type, patient demographic, and hospital visit characteristics were all associated with receiving ≥1 vaccine dose during hospitalization. The most common vaccines administered were the birth dose of hepatitis B vaccine and influenza vaccines, with <2% of hospitalizations involving the administration of any other recommended childhood vaccines. Furthermore, there was considerable variability in the proportion of hospitalized children who received ≥1 vaccine dose by hospital.

This study highlights several important aspects of inpatient vaccine delivery. First, certain doses of childhood vaccines were administered more than others, with the birth dose of hepatitis B vaccine and influenza vaccine doses constituting the majority of vaccine doses administered to hospitalized children. This suggests that there are existing systems in place to deliver these vaccines to hospitalized children, consistent with previous literature.[14,19,21,23,25,26,37,40]

There are several reasons why influenza vaccination during hospitalization may be prioritized compared with other childhood vaccines. First, children may not have seen their primary care provider during the current influenza season, and therefore, hospitalization affords an opportunity to vaccinate.[19,41–43] Additionally, parent report of their child's influenza vaccine status may be more trusted[44–46] compared with other childhood vaccines[10,47–50] because parents only need to recall if their child has received a single vaccine in the past year, compared with the entire CDC vaccine schedule with >20 vaccine doses by 18 months of age.[30] Furthermore, the Joint Commission has identified inpatient influenza vaccination as a clinical quality measure for hospitals, which may lead to prioritization of influenza vaccine delivery.[51] Expansion of quality measures related to noninfluenza vaccines may help catalyze efforts to increase inpatient vaccinations.

Of note, the PHIS database does not contain individual vaccine records or information about vaccine eligibility aside from age. This limitation highlights the well-documented challenge of identifying who is vaccine eligible during hospitalization.[10,11,13,14,16] With the growth of population-based IISs nationally, better integration of IISs with hospital electronic medical records and administrative databases such as PHIS could help in identifying opportunities to vaccinate hospitalized children.[52] Use of IIS to identify opportunities to vaccinate children during hospitalization aligns with a key objective for the *Healthy People 2030* goals to increase the proportion of people with vaccination records in an IIS.[4] Although PHIS does not contain individual vaccine eligibility data,

TABLE 3 Demographic Characteristics of Children Administered ≥ 1 Routine Childhood Vaccine Doses, Excluding Influenza and Birth Dose of the Hepatitis B Vaccine, During Hospitalization

	Received ≥1 Vaccine, $N = 28\,912$	Received 0 Vaccines, $N = 1\,507\,428$	Odds Ratio of Children Who Were Administered ≥1 Vaccine Compared With Children Who Were Administered No Vaccines
Admit age, *n* (%)			
<2 mo	14 061 (49)	282 338 (19)	8.9 (8.4–9.4)
2–18 mo	5880 (20)	273 978 (18)	3.8 (3.6–4.1)
19–35 mo	1007 (3)	141 801 (9)	1.3 (1.2–1.4)
3–6 y	1329 (5)	236 602 (16)	Reference
7–12 y	3091 (11)	280 797 (19)	2.0 (1.8–2.1)
≥13 y	3544 (12)	291 912 (19)	2.2 (2.0–2.3)
Age, mean (SD)	3.2 (3.2–3.3)	5.6 (5.6–5.6)	<0.001
Sex (female), *n* (%)	12 698 (44)	697 732 (46)	0.9 (0.9–0.9)
Race and ethnicity, *n* (%)			
Non-Hispanic White	11 499 (40)	656 219 (44)	Reference
Non-Hispanic Black	6940 (24)	270 876 (18)	1.5 (1.4–1.5)
Hispanic	5047 (17)	301 500 (20)	1.0 (0.9–1.0)
Other	2730 (9)	136 432 (9)	1.1 (1.1–1.2)
Missing	2696 (9)	142 401 (9)	—
Insurance, *n* (%)			
Private	10 392 (36)	661 330 (44)	Reference
Public	18 172 (63)	822 564 (55)	1.4 (1.4–1.4)
Missing	348 (1)	23 534 (2)	—
PMCA, *n* (%)			
No chronic disease	7136 (25)	625 163 (41)	Reference
Noncomplex chronic	5928 (21)	372 616 (25)	1.4 (1.3–1.4)
Complex chronic	15 848 (55)	509 649 (34)	2.7 (2.6–2.8)
ICU stay, yes, *n* (%)	6487 (22)	181 544 (12)	2.1 (2.1–2.2)
Influenza season, *n* (%)			
May to August	5960 (21)	461 217 (31)	Reference
September to April	22 952 (79)	1 046 211 (69)	1.7 (1.6–1.7)
Hospital LOS, mean LOS (SD)	54.9 (68.1)	3.8 (7.7)	<0.001
Categorical LOS, *n* (%), d			
<3	6021 (21)	953 415 (63)	Reference
3–7	3839 (13)	399 267 (26)	1.5 (1.5–1.6)
8–30	3675 (13)	136 013 (9)	4.3 (4.1–4.5)
>30	15 377 (53)	18 733 (1)	130.0 (125.7–134.4)

—, not applicable.

≥1 vaccine doses were delivered in only 12.9% of hospitalizations, well below current estimates of the proportion of hospitalized children who are undervaccinated (27% to 84%).[10–14] This discrepancy, and the variability between hospitals in vaccine administration identified in this study, suggests there are likely missed opportunities to vaccinate hospitalized children on a national scale.

Using administrative data from 49 children's hospital, we identified significant variation in vaccine administration by hospital. Even after adjusting for state-level vaccination rates, hospital-level demographic characteristics, and hospital-level case mix, some hospitals were high performers with regards to administering vaccines. It is noteworthy that some hospitals (hospitals 46–49) were high performers across different types of vaccines. This finding suggests that these hospitals may have developed effective systems to identify undervaccinated hospitalized children and deliver needed vaccines to them. Conversely, there were several hospitals that delivered no vaccines of certain types, particularly live vaccines (rotavirus, MMR, and varicella) and HPV. A better understanding of existing mechanisms to vaccinate hospitalized children across hospitals, such as hospital-level vaccination policies and strategies (eg, vaccine prompts, workflow processes), may help elucidate why children at some hospitals were more likely to receive vaccines and identify key targets for quality improvement efforts to improve inpatient vaccine delivery.[29]

There may be factors that are external to hospitals that contribute to inpatient vaccine rates. For example, although 49 states have an IIS, there is variation by state in the proportion of children who participate.[53] A higher proportion of children participating in IIS may

TABLE 4 Sensitivity Analysis of Demographic Characteristics of Children ≥2 Months Who Received ≥1 Noninfluenza, Nonbirth Dose Hepatitis B Vaccines During Hospitalization

	Received ≥ 1 Vaccine, $N = 14\,851$	Received 0 Vaccines, $N = 1\,225\,092$	Odds Ratio of Children Who Received ≥1 Vaccine Compared With Children Who Received No Vaccines
Admit age, *n* (%)			
2–18 mo	5880 (40)	273 978 (22)	3.8 (3.6–4.1)
19–35 mo	1007 (7)	141 902 (12)	1.3 (1.2–1.4)
3–6 y	1329 (9)	236 602 (19)	Reference
7–12 y	3091 (21)	280 798 (23)	2.0 (1.8–2.1)
≥13 y	3544 (24)	291 912 (24)	2.2 (2.0–2.3)
Age, mean (SD)	6.3 (6.2–6.4)	6.9 (6.9–6.9)	<0.001
Sex (female), *n* (%)	6348 (43)	569 450 (47)	0.9 (0.8–0.9)
Race and ethnicity			
Non-Hispanic White	5912 (40)	541 254 (44)	Reference
Non-Hispanic Black	3834 (26)	228 527 (19)	1.5 (1.5–1.6)
Hispanic	2548 (17)	245 861 (20)	0.9 (0.9–1.0)
Other	1396 (9)	104 272 (9)	1.2 (1.2–1.3)
Missing	1161 (8)	105 178 (9)	—
Insurance			
Private	5114 (34)	526 369 (43)	Reference
Public	9532 (64)	678 408 (55)	1.4 (1.4–1.5)
Missing	205 (1)	20 315 (2)	—
PMCA			
No chronic disease	4649 (31)	401 538 (33)	Reference
Noncomplex chronic	3221 (22)	342 195 (28)	0.8 (0.8–0.9)
Complex chronic	6981 (47)	481 359 (39)	1.3 (1.2–1.3)
ICU stay, yes, *n* (%)	3730 (25)	163 253 (13)	2.2 (2.1–2.3)
Season, *n* (%)			
April to September	7350 (49)	587 989 (48)	Reference
October to March	7501 (51)	637 103 (52)	0.9 (0.9–1.0)
Hospital LOS, mean (SD)	21.1 (51.2)	3.4 (6.7)	<0.001
Categorical LOS, *n* (%), d			
<3	5922 (40)	799 182 (65)	Reference
3–7	3671 (25)	323 982 (26)	1.5 (1.5–1.6)
8–30	2833 (19)	92 745 (8)	4.1 (3.9–4.3)
>30	2425 (16)	9183 (1)	35.6 (33.8–37.5)

—, not applicable.

make it easier for hospitals to identify needed vaccinations and to communicate inpatient vaccinations to the medical home. Another important factor that has yet to be fully explored is the cost to hospitals and patients who receive vaccines during hospitalization. Future work is needed to identify effective strategies used by high-performing hospitals and key contextual factors associated with high performance to improve vaccine delivery to hospitalized children nationally.

Another key finding was that certain children had higher odds of being administered ≥1 vaccine during hospitalization: children <3 years or >6 years of age, children who were identified as Black or "other" race, children with public insurance, those with higher levels of medical complexity, and those who had a LOS >3 days. These characteristics, including non-Hispanic Black race and having public insurance, are consistent with population-level estimates associated with lower vaccine coverage.[54] We hypothesize that differences in vaccine receipt during hospitalization may also be due to younger children and children with longer LOS becoming vaccine eligible during hospitalization or the medical team having additional time to identify the need for vaccination. Furthermore, barriers to accessing vaccinations in traditional settings, such as primary care, may be higher for children with public insurance[55–57] and medical complexity,[58,59] which may increase the need for catch-up vaccines in these populations and make inpatient vaccination a higher priority.

Since the onset of the coronavirus disease 2019 pandemic in March 2020, the need for this work is particularly relevant. Childhood vaccination rates have declined nationally because of a reduction in outpatient vaccinations during the coronavirus disease 2019 pandemic,[60,61] increasing the risk of vaccine-preventable disease in children.[62] As a result, there is

renewed interest in strategies to capture all available opportunities to provide routine childhood vaccinations, including hospitalization. With 3 million pediatric hospitalizations annually,[63,64] developing robust systems to identify and provide vaccines during hospitalization has the potential to improve childhood vaccination rates.

This study has several limitations. The primary limitation is the lack of individual vaccine eligibility within the data set. To help mitigate this, we only included children who were age eligible for vaccines and adjusted for state-level vaccination rates. By including all children who were age eligible per the CDC routine and catch-up vaccination schedules, rather than only those who were vaccine eligible, the calculated vaccination rates are likely lower than the true rates in vaccine-eligible children. Secondly, exclusion criteria for the study were broad to encompass all children who had conditions that would alter the routine childhood vaccination schedule per the ACIP recommendations.[18] Realistically, many of these children would still have been eligible for several routine vaccines. Without vaccine eligibility data, we are unable to quantify missed opportunities by hospital or by individual.

Another limitation is that the PHIS database contains administrative billing data and is subject to the data quality issues inherent in database management.[65] The Children's Hospital Association, which administers PHIS, conducts data quality checks to minimize errors to the accuracy and completeness of the data.[66] Lastly, PHIS is specific for children's hospitals and findings may not be generalizable to other settings such as community hospitals or children's units within general hospitals.

CONCLUSIONS

In this national study of US children's hospitals, we examined vaccine administration of all recommended childhood vaccinations during hospitalization. We identified several significant factors associated with vaccine administration in hospitalized children: the type of vaccine, patient demographic characteristics, and hospital visit characteristics. Additionally, there was significant variability in vaccine delivery by hospital. Future work should identify strategies to improve rates of vaccines delivered during hospitalization nationally. This study highlights the need to improve integration of vaccine eligibility data into inpatient clinical and administrative databases to accurately identify vaccine-eligible children.

ABBREVIATIONS

ACIP: Advisory Committee on Immunization Practices
CDC: Centers for Disease Control and Prevention
CI: confidence interval
CTC: Clinical Transaction Classification
DTaP: diphtheria, tetanus, acellular pertussis
HPV: human papillomavirus
ICD-10: *International Statistical Classification of Diseases and Related Health Problems, 10th Revision*
IIS: Immunization Information System
IPV: inactivated poliovirus
IQR: interquartile range
LOS: length of stay
MMR: measles, mumps, rubella
PHIS: Pediatric Health Information System
PMCA: Pediatric Medical Complexity Algorithm
UTD: up to date

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