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Identifying Risk Factors for Underimmunization by Using Geocoding Matched to Census Tracts: A Statewide Assessment of Children in Hawaii

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ABSTRACT

OBJECTIVE. Obtaining childhood immunization coverage data for small geographic areas is difficult and resource-intensive, especially in the absence of comprehensive immunization registries. To identify factors that are associated with delayed immunization, we collected school-entry immunization records statewide and used geocoding to link to publicly available census tract sociodemographic data.

METHODS. Immunization records were reviewed for children who were enrolled in all public and private school kindergarten programs in Hawaii in the 2002–2003 school year; immunization status at the time of the second birthday was determined. The main outcome variable was up-to-date status for the 4:3:1:3:3 vaccination series (4 doses of diphtheria-tetanus-pertussis, 3 doses of polio, 1 dose of measles-mumps-rubella, 3 doses of *Haemophilus influenzae* type b, and 3 doses of hepatitis B vaccines). Children's home addresses were geocoded to census tracts; coverage rates by tract were mapped, and sociodemographic data from Census 2000 files were used to identify factors that were associated with delays in immunization.

RESULTS. Records were obtained for 15 275 of 15 594 children registered in Hawaii kindergartens. Overall, 78% had completed their 4:3:1:3:3 series by their second birthday. Risk factors for delayed immunization included delayed immunization at 3 months of age, living in Maui County, living in a neighborhood where a low proportion of adults had postsecondary education, and living in a neighborhood where a high proportion of households spoke a language other than English at home. The majority (80%) of underimmunized children would have required only 1 additional visit to bring them up-to-date.

CONCLUSIONS. Retrospective review of kindergarten-entry immunization data revealed geographic areas with lower immunization coverage, and geocoding to census tracts identified associated sociodemographic risk factors. This is a practical method for state or city health departments to identify pockets of need and to direct resources appropriately.

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Key Words
immunization rates, preschool child, child health services, immunization programs

Abbreviations
NIS—National Immunization Survey
USGS—United States Geological Survey
DTP—diphtheria-tetanus-pertussis vaccine
MMR—measles-mumps-rubella vaccine
Hib—*Haemophilus influenzae* type b vaccine
hepB—hepatitis B vaccine
OR—odds ratio
CI—confidence interval

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VACCINES HAVE BEEN cited as 1 of the great public health successes of the 20th century,[1] and vaccine coverage rates among young children are a key measure used to monitor disease-control programs. In summer 2002, a decrease in vaccination coverage among children who resided in Hawaii was identified through the National Immunization Survey (NIS).[2,3] In response to this finding, the Hawaii State Department of Health decided to better characterize underimmunized children in the state by demography and risk factors.

Surveys to assess childhood immunization coverage are both challenging and expensive. Because only 3% to 5% of households include an eligible child (eg, aged 19–35 months), substantial numbers of households need to be contacted for each successful interview.[4] Given the unreliability of parental recall for vaccination, follow-up with providers is also required.[5] NIS staff conduct this follow-up and provide reliable estimates of coverage at the state level, but NIS has limited utility for assessing coverage for smaller geographic areas. Neither door-to-door nor random-digit-dialing telephone surveys were deemed feasible for this state-level assessment, and a comprehensive immunization registry is still under development in Hawaii.

We determined that a kindergarten retrospective assessment might provide the most useful information at an affordable cost in terms of time and resources.[6,7] Reporting of individual student immunizations at school entry is legally mandated in Hawaii, and these data can be collected by school health aides and forwarded to the State Immunization Program. Because no sociodemographic data are collected on school immunization records, we geocoded children's residential addresses at school entry and mapped these to census tracts. Census tract–level data for multiple sociodemographic variables are publicly available.[8] Using census tract–level data to evaluate the association of socioeconomic status to health has been widely advocated and used for health outcomes[9–11] but has not been used before in evaluating childhood immunization coverage. We present an assessment of risk factors for underimmunization for the cohort of children who entered kindergarten in all Hawaii public and private schools in 2002, assessed retrospectively by determining vaccination status at 2 years of age and geocoding addresses to census tract data.

METHODS

Immunization Data

We abstracted data from school-entry immunization records for children who were enrolled in the 194 public and 108 private Hawaii kindergarten programs for the 2002–2003 school year. All children who enter kindergarten in Hawaii are required to submit documentation of immunizations received, and schools maintain this documentation in compliance with the state's school immunization law. Public health nurses and school health aides in public schools were requested to forward this information to the Hawaii Department of Health. Private schools were contacted both through an association of private schools and individually as needed. Records were not verified with provider records. Data collected included the student's date of birth; residential address; and dates of vaccination against diphtheria-tetanus-pertussis, polio, measles-mumps-rubella, *Haemophilus influenzae* type b, hepatitis B, and varicella. Any religious or medical exemptions to vaccination were recorded. Data were not available from home-schooled children; however, there were only 142 (<1%) registered home-schooled kindergartners in the 2002–2003 school year (Hawaii Department of Education, unpublished data, 2004). Data were entered by using the Clinic/Provider Assessment Software Application (2.3; Centers for Disease Control and Prevention/National Center for Immunization and Respiratory Diseases, Atlanta, GA).

Geocoding and Matching to Census Tracts

Residential addresses were assigned to census tracts by using a hierarchy of 3 processes: (1) geocoding and automatic matching to census tracts, (2) manual identification of locations and manual assignment of census tract, and (3) stratified probabilistic assignment of census tracts on the basis of zip code alone. Geocoding is a process that converts address information (street address, city name, and zip code) to a latitude and longitude coordinate by using standard reference data files of roads and block address ranges. We initially geocoded residential addresses from the school immunization records with ArcView 8.3 (ESRI, Redlands, CA) by using multiple reference data files, including 2000 Census Topically Integrated Geographic Encoding and Referencing System, US Geological Service (USGS) roads (USGS 1983 Digital Line Graphs), and the Honolulu Land Information System (City and County of Honolulu 2005). The appropriate census tract was identified for each geocoded location.

Certain cases could not be automatically geocoded for multiple reasons (eg, provision of zip code only, a post office box only, an unlisted address in any of the reference data files). In these cases, 2 manual methods were used: zip code alone if the zip code fell entirely within a census tract or Internet searching of specific addresses by using Microsoft MapPoint (Microsoft Corporation, Redmond, WA) and use of landmarks (eg, street or highway intersections) to identify which census tract included that address.

For records that could not be geocoded or manually assigned a census tract, we developed an algorithm to assign tracts on the basis of zip code (the zip code of the child's home where available or the zip code of the school when no residential address information was available). This was based on a weighted probabilistic assignment to census tract, with the weights proportional to the population sizes of census tracts that fall within a given zip code boundary. The terms "neighborhood" and "census tract" are used interchangeably in the remainder of this article.

Definition of Variables

Children were considered up-to-date for immunization at 2 years of age when they had received 4 doses of diphtheria and tetanus toxoids and pertussis vaccine (DTP or DTaP; henceforth referred to as DTP), 3 doses of poliovirus (polio) vaccine, 1 dose of measles-mumps-rubella (MMR) vaccine, 3 doses of *Haemophilus influenzae* type b vaccine (Hib), and 3 doses of hepatitis B vaccine (hepB). This is referred to as the 4:3:1:3:3 vaccine series. When <3 doses of Hib had been administered but at least 1 dose had been administered after 15 months of age, the child was also considered to be up-to-date for Hib. For 3 large private schools that did not collect information about Hib vaccinations on the school record (because it was not legally required), children were considered up-to-date when they had the remaining elements of the 4:3:1:3:3 series complete (ie, DTP, polio, MMR, and hepB). Analyses were repeated, excluding children from these schools with no statistically significant difference in findings. Children with documented religious exemptions, accounting for <1% of all records, were excluded from the data set. Children with a medical exemption for a specific vaccine (<0.1% of records) were treated as up-to-date for that vaccine.

Although varicella vaccine was recommended by the Advisory Committee on Immunization Practices for this cohort at the time when they were infants,[12] the vaccine was relatively new and was not included in the assessment of up-to-date coverage. Sociodemographic variables for census tracts reflected characteristics of the entire population of the tract, not simply households with kindergartners. We examined census data on median household income, rural versus urban status, racial makeup of tracts, languages spoken at home, and level of education. The median household income variable was defined by quartile; all other census tract variables were dichotomized as either high (≥25% of the tract population with a given characteristic) or low (<25% of the tract population with a given characteristic). Up-to-date coverage results are also shown by type of school later attended, defined as either public or private school, which may be a rough proxy indicator of household socioeconomic status. However, because schooling decisions reflect a range of noneconomic factors as well, this variable was not included in the main contingency analysis.

We assumed that no limit existed for the number of vaccines that might have been administered at any given encounter in calculating the number of visits required to bring a child up-to-date (ie, up to 5 different vaccines could be administered but no more than 1 dose of a given series). Because only 1 dose of Hib is required after 15 months of age, children with <3 doses and none after 15 months of age were considered to need only 1 additional dose to catch up.

Statistical Methods

Data were analyzed by using SAS 8.02 (SAS Institute, Inc, Cary, NC). Contingency table analysis based on χ^2 statistics was used to investigate the associations between different factors and being up-to-date for the 4:3:1:3:3 series at the time of the second birthday. For selected parameters, >1 variable was assessed. For example, household economic status by census tract was considered by both median household income quartile and proportion of households living in poverty; education levels were considered by both the proportion of adults (≥18 years) with a bachelor's degree or higher and the proportion of adults with less than a high school diploma. When the multivariable model was developed, only the variable more strongly associated with up-to-date status for each parameter was included in the model. Multivariable analysis was based on generalized mixed-effects models, considering the multilevel structure of the data (individual level and census tract level). Models with interaction terms were considered. Multiple second-order interactions were statistically significant, but their effects were inconsequential in practice. Therefore, only the main-effects model is considered in this article.

RESULTS

Immunization records were received from 179 (100%) regular public schools, 90 (83%) of 108 private schools, and 11 (73%) of 15 charter schools. The majority of the nonreporting schools had limited numbers enrolled: overall, records were received for 15 409 (99%) of 15 594 children enrolled in kindergarten. After exclusion of students with a religious exemption, 15 275 records were used for data analysis.

A total of 12 478 (82%) records were geocoded by using ArcView and Streetmap (www.streetmap.com/) or USGS Roads; 680 (4%) were manually geocoded to a census tract on the basis of a street or post office box address, 1112 (7%) were assigned a tract on the basis of the zip code of the home address, and 1012 (7%) were assigned a tract on the basis of the zip code of the school address.

Overall, 78% of children were up-to-date for the 4:3:1:3:3 series by their second birthday and 87% by their third birthday (Table 1). Coverage at 2 years of age ranged from 84% for DTP to 96% for Hib. Varicella vaccine had been administered to 69% of children aged 2 years and 79% of children aged 3 years.

Up-to-date coverage for the 4:3:1:3:3 series varied by

TABLE 1 **Up-to-Date Status for 4:3:1:3:3 Series and Individual Vaccines, Ages 24 and 36 Months, Assessed Retrospectively (*N* = 15 275)**

Vaccine/Series	Up-to-Date by Age 24 mo		Up-to-Date by Age 36 mo	
	n	% (95% CI)	*n*	% (95% CI)
Up-to-date 4:3:1:3:3	11 854	77.6 (±0.3)	13 250	86.7 (±0.3)
4 DTP	12 766	83.6 (±0.3)	13 972	91.5 (±0.2)
3 polio	13 996	91.6 (±0.2)	14 603	95.6 (±0.2)
1 MMR	14 351	94.0 (±0.2)	14 737	96.5 (±0.1)
3 Hib[a]	14 670	96.0 (±0.2)	14 676	96.1 (±0.2)
3 Hib[b]	14 378	96.0 (±0.2)	14 454	96.5 (±0.1)
3 hepB	14 207	93.0 (±0.2)	14 527	95.1 (±0.2)
VZV	10 556	69.1 (±0.4)	11 995	78.5 (±0.3)

VZV indicates varicella zoster virus.

[a] Three large private schools did not report Hib status. These students were assumed to be up-to-date for Hib when they were up-to-date for DTP, polio, MMR, and hepB.

[b] Students from 3 large private schools that did not report Hib status were excluded from the data analysis.

both individual and census tract characteristics (Table 2). Coverage was highest among children who had been up-to-date at 3 months of age, those who later attended private school, those from census tracts with the top median household income quartile, and those who lived in Kauai.

Figure 1 illustrates all census tracts in the state and the proportion of children who were up-to-date at 2 years of age. Areas with lower proportions of children up-to-date include east Hawaii, a substantial proportion of Maui, Lanai, and parts of central and northern Oahu.

Contingency table analysis demonstrated that the factor that was most strongly associated with up-to-date status at 2 years of age was having immunizations up-to-date at 3 months of age (Table 3). Children who were already behind by 3 months of age had an odds ratio (OR) of 7.1 (95% confidence interval [CI]: 6.5–7.8) for underimmunization at 2 years of age. The county of residence was also significantly associated with underimmunization as follows, compared with the reference county of Oahu: Maui, OR: 1.4 (95% CI: 1.3–1.6); Hawaii, OR: 1.2 (95% CI: 1.1–1.4); and Kauai, OR: 0.8 (95% CI: 0.7–1.0). Children from neighborhoods with a high proportion of Asian residents were more likely to be up-to-date at 2 years of age, whereas other race/ethnicity concentrations and a high proportion of foreign-born residents were not associated with up-to-date status. Children from neighborhoods where a high proportion of households spoke a language other than English at home or were living in poverty were more likely to be behind on their immunizations. Each decline in median household income quartile was associated with an increased risk for being underimmunized. Higher education levels and more rural areas were significantly associated with improved up-to-date status.

Factors that remained statistically significant on multivariate, multilevel analysis included being up-to-date at 3 months of age, county of residence (with Maui having the lowest coverage), median household income, proportion of Asian residents, proportion speaking a language other than English at home, education levels, and proportion of households classified as rural (Table 3). Children from neighborhoods with a higher proportion of Native Hawaiian/Pacific Islanders were more likely to

TABLE 2 **Characteristics of Study Population and Up-to-Date Status for the 4:3:1:3:3 Series at Age 24 Months**

Characteristics	Study Population		4:3:1:3:3 Series Up-to-Date by Age 24 mo	
	n	%	*n*	% (95% CI)
Individual characteristics				
County				
Oahu	10 988	71.9	8647	78.7 (±0.4)
Hawaii	1840	12.0	1377	74.8 (±1.0)
Maui	1730	11.3	1245	72.0 (±1.1)
Kauai	717	4.7	585	81.6 (±1.4)
Up-to-date at 3 mo of age				
Yes	12 635	82.7	10 699	84.7 (±0.3)
No	2640	17.3	1155	43.8 (±1.0)
Type of school later attended				
Public and charter	13147	86.1	10056	76.5 (±0.4)
Private	2128	13.9	1798	84.5 (±0.8)
Census tract characteristics				
Household income, median				
Quartile 1 ($2499–$37 037)	3306	22.0	2398	72.5 (±0.8)
Quartile 2 ($37 038–$49 115)	3942	26.0	3007	76.3 (±0.7)
Quartile 3 ($49 116–$63 170)	4467	29.0	3521	78.8 (±0.6)
Quartile 4 ($63 171–$127 437)	3560	23.0	2928	82.3 (±0.6)
Proportion Asian				
High[a]	10 546	69.0	8341	79.1 (±0.4)
Low[b]	4729	31.0	3513	74.3 (±0.6)
Proportion Hawaiian/Pacific Islander				
High[a]	1051	6.4	821	78.1 (±1.3)
Low[b]	14 224	93.6	11 033	77.6 (±0.3)
Proportion foreign-born[c]				
High[a]	3380	22.1	2593	76.7 (±0.7)
Low[b]	11 895	77.9	9261	77.9 (±0.4)
Proportion who speak non-English language at home				
High[a]	11 646	76.2	8993	77.2 (±0.4)
Low[b]	3629	23.7	2861	78.8 (±0.7)
Proportion of households in poverty				
High[a]	757	5.0	563	74.4 (±1.6)
Low[b]	14 518	95.0	11 291	77.8 (±0.3)
Proportion of households classified as rural				
High[a]	1553	10.2	1166	75.1 (±1.1)
Low[b]	13 722	89.2	10 688	77.9 (±0.4)
Proportion aged ≥18 years with bachelor's degree or higher				
High[a]	6523	42.7	5246	80.4 (±0.5)
Low[b]	8752	57.3	6608	75.5 (±0.5)
Proportion aged ≥18 years that did not complete high school				
High[a]	2821	18.5	2123	75.3 (±0.8)
Low[b]	12 454	81.5	9731	78.1 (±0.4)

[a] High is defined as ≥25% of the population within the census tract.

[b] Low is defined as <25% o the population with the census tract.

[c] Born outside the United States and its territories.

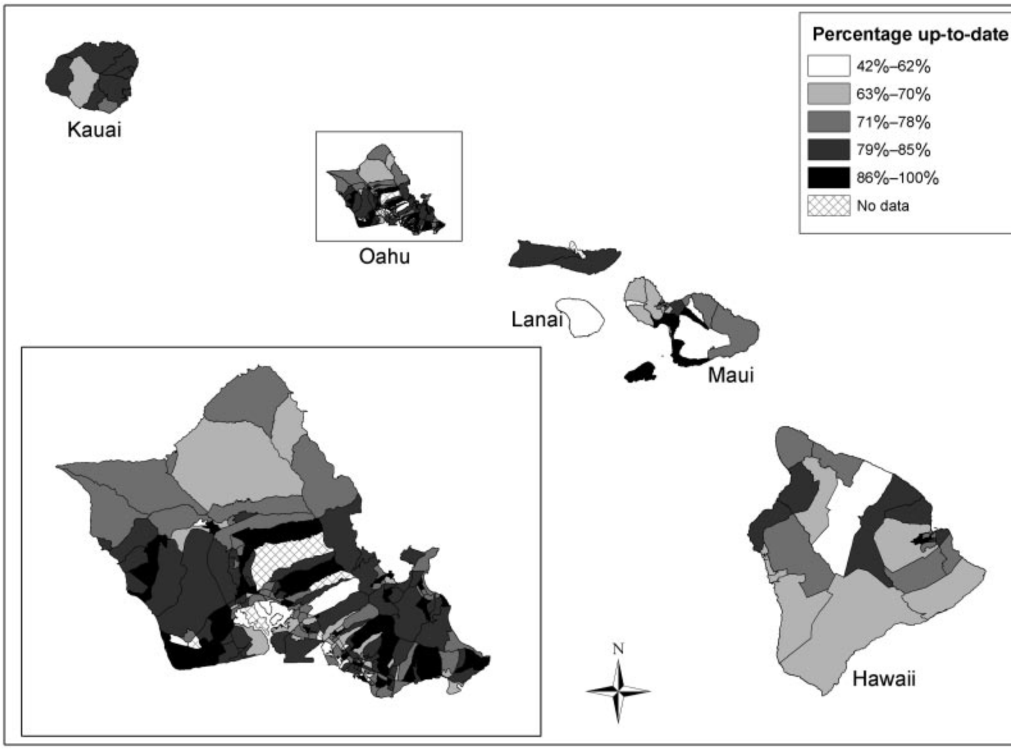

FIGURE 1
Proportion of children aged 24 months who were up-to-date on the 4:3:1:3:3 series according to census tract.

be up-to-date after adjustment for other factors (adjusted OR: 0.6; 95% CI: 0.5–0.8).

Among the 3421 children with incomplete immunizations at 2 years of age, the majority (80%) would have needed only 1 additional visit to be up-to-date, 9% would have required 2 visits, 8% would have required 3 visits, and 4% would have required 4 visits. A total of 98% of children were up-to-date by the time of school entry.

DISCUSSION

Our retrospective evaluation among kindergarten students who resided in Hawaii documented coverage for the 4:3:1:3:3 vaccine series among children aged 2 years as 78%. The single most important predictor of up-to-date status at 2 years of age was being up-to-date at 3 months of age. Significant variation occurred in coverage by county and census tract, with Maui in particular having lower coverage. Census tract–level characteristics that were associated with an incomplete primary vaccine series by 2 years of age included low income and education and a high concentration of households speaking a language other than English (which may be a proxy for more recent immigration). Consistent with national data, the majority of underimmunized children could have been brought fully up-to-date with only 1 visit,[13] and virtually all children were up-to-date by the time of school entry.

The strong predictive value of immunization delays during the first 3 months of life has been documented in other studies.[14–16] Among our study population, children who had not yet received their first DTP, Hib, and hepB vaccinations by 3 months of age composed 17% of the population but accounted for 77% of all children who were not up-to-date by 2 years of age. Although identifying children at risk on the basis of sociodemographic factors can be challenging for individual providers, immunization history during the first 3 months is easily viewed in a patient chart, and a delay can be flagged as a risk factor for the duration of that child's preschool years. Vaccine providers and other providers who view immunization records (eg, staff of the Women, Infants, and Children program) should be encouraged to identify these children throughout their early years, flag their records, and provide additional support and reminders to ensure that they receive age-appropriate vaccinations.

The variation in coverage by county identified by our study is consistent with subjective impressions of health department staff. Anecdotal information suggests that Maui's lower immunization rates might be explained, in part, by greater participation in alternative medicine practices and higher levels of skepticism among parents about immunization benefits.

Identification of census tracts with lower immunization coverage allows public health staff to target their efforts both geographically and on the basis of sociode-

TABLE 3 **Factors Associated With Not Being Up-to-Date for 4:3:1:3:3 Series at Age 24 Months: Univariate and Multivariate Analysis**

Characteristic	Univariate Analysis, Unadjusted OR (95% CI)	Multivariate Analysis, Adjusted OR (95% CI)
Individual characteristics		
County		
Oahu	Reference	Reference
Hawaii	1.2 (1.1–1.4)	1.2 (1.0–1.5)
Maui	1.4 (1.3–1.6)	1.4 (1.2–1.7)
Kauai	0.8 (0.7–1.0)	1.0 (0.7–1.2)
Up to date at 3 mo of age		
Yes	Reference	Reference
No	7.1 (6.5–7.8)	7.4 (6.7–8.1)
Census tract characteristics		
Household income, median		
Quartile 1	1.8 (1.6–2.0)	1.2 (1.0–1.4)
Quartile 2	1.4 (1.3–1.6)	1.0 (0.9–1.2)
Quartile 3	1.2 (1.1–1.4)	0.9 (0.8–1.1)
Quartile 4	Reference	Reference
Proportion living in poverty		
High[a]	1.2 (1.0–1.4)	Not in model
Low[b]	Reference	
Proportion Asian		
High[a]	Reference	Reference
Low[b]	1.3 (1.2–1.4)	1.4 (1.2–1.5)
Proportion Hawaiian/Pacific Islander		
High[a]	1.0 (0.8–1.1)	0.6 (0.5–0.8)
Low[b]	Reference	Reference
Propotion foreign-born[c]		
High[a]	1.1 (1.0–1.2)	Not in model
Low[b]	Reference	
Proportion who speak non-English language at home		
High[a]	Reference	Reference
Low[b]	0.9 (0.8–1.0)	0.8 (0.7–1.0)
Proportion households classified as rural		
High[a]	Reference	Reference
Low[b]	1.2 (1.0–1.3)	1.3 (1.1–1.6)
Proportion aged ≥18 years with bachelor's degree or higher		
High[a]	0.8 (0.7–0.8)	0.8 (0.7–0.9)
Low[b]	Reference	Reference
Proportion aged ≥18 that did not complete high school		
High[a]	1.2 (1.1–1.3)	Not in model
Low[b]	Reference	

[a] High is defined as ≥25% of the population within the census tract.
[b] Low is defined as <25% of the population within the census tract.
[c] Born outside the United States and its territories.

mographic risk factors. Poverty and low income are associated with poor health outcomes, including childhood immunization status.[17,18] The Vaccines for Children program ensures that poor, uninsured, and (in some states) underinsured families do not have to pay directly for vaccines, but barriers are often associated with low socioeconomic status beyond direct costs. Lack of knowledge of vaccine schedules, transportation difficulties, clinic hours and waiting times, and challenges in navigating the logistics of the health care system all can make children in low-income families less likely to be immunized on time.

Although race and ethnicity have been documented in multiple studies to be associated with vaccination status, this has usually been examined in terms of white, black, and Hispanic groups.[19,20] Hawaii's unique racial/ethnic mix makes findings from other parts of the United States less applicable to our setting. For certain health indicators in Hawaii (eg, life expectancy, infant survival), Asians have the highest measures and Native Hawaiian/Pacific Islanders the lowest.[21] This was true for infant immunization coverage in this study as well but only in the univariate analysis. After adjusting for household income, we determined that living in a neighborhood with a high proportion of Native Hawaiian/Pacific Islanders was significantly associated with higher immunization rates at 2 years of age. This is important because it indicates that economic disparities might be the primary cause of poor health-measure rates among Native Hawaiians/Pacific Islanders. We encourage other investigators to control for possible economic confounding when examining determinants of health among these populations.

Our study also found that children from neighborhoods with high concentrations of foreign-born individuals were no less likely to be up-to-date for their primary series; however, children from neighborhoods where high numbers of households spoke a language other than English at home were at risk. This suggests that language barriers or health care access barriers associated with more recent immigration might be an obstacle for families to vaccinating their children on schedule.

Our experience with this kindergarten retrospective assessment of vaccination status might be useful to other states that seek more geographically detailed data than are available from extant sources. Although a rich source of data for national trends and state-level coverage estimates, the NIS does not allow assessment of limited geographic areas within a state and allows only limited assessment of sociodemographic characteristics in the public use data files because of confidentiality safeguards. In the absence of a good sampling frame to identify a representative sample of children aged 2 years, random-digit telephone dialing and household surveys to identify these children are prohibitively expensive and too labor-intensive for many state health departments to undertake. Immunization registries do not yet provide complete enough information in most areas of the country to permit surveillance of population coverage rates.[22] We were able to complete our assessment using minimal resources beyond existing health department staff time (contracted data entry clerks for 6 person-months).

Retrospective assessments of the immunization status of children entering school were supported by federal funds and conducted throughout the United States for 1990–1994.[5] This type of assessment was simple and inexpensive and allowed coverage levels to be assessed for local areas.[6] Two main disadvantages led to the phasing out of federal support: they provided coverage-level estimates for 3 to 4 years before data collection, and the accuracy of school immunization records was uncertain. In particular, certain areas reported that to save time, school staff would record only immunizations that were necessary for school entry rather than each vaccine received; therefore, certain vaccinations received before 2 years of age might not be documented on school records if the child otherwise qualified to enter school.[5]

For Hawaii, concerns about the quality of school vaccination records have been minimized by training school health staff and conducting a standardized record audit among a sample of schools each year. A more serious limitation of using school records to assess retrospectively the immunization status of children aged 2 years was the lack of sociodemographic information on the school immunization records. No information that reflects socioeconomic status, race, immigration status, or health insurance status is collected, limiting our ability to identify risk factors for underimmunization and target populations for programmatic interventions. However, we determined that using residential addresses geocoded to census tracts allowed us to examine a spectrum of social, demographic, economic, and racial factors at the neighborhood level as contributors to underimmunization.

Our study had a number of limitations. Immunization records were taken from school records and not verified with providers, and these records were collected to verify up-to-date status at school entry, not at 2 years of age. Therefore, inaccuracies might exist in the dates of immunizations or the documentation of immunizations that were not required for school entry. In particular, the strong association of up-to-date status at 3 months of age with up-to-date status at 2 years of age could be partially attributable to missing documentation of early doses that were actually received. Another potential limitation is that the child's current residential address was used to link to census tract data. Approximately 14% of Hawaii's households move each year (64% of these within the same county),[23] so for some families, the residential address at kindergarten entry is different from that at 2 years of age. Our use of the census tract data requires the assumption that the majority of the families who moved did so from 1 neighborhood to another that was similar in terms of socioeconomic status, racial/ethnic, and immigrant composition. We were unable to evaluate the effect on underimmunization of health insurance status, health care provider characteristics, or barriers in the health care delivery system. These factors have been identified as having important associations with underimmunization and should be considered when interventions to improve immunization coverage are implemented.[14,15,24–26]

CONCLUSIONS

Our study has identified sociodemographic risk factors and specific neighborhoods that may benefit from public health strategies to increase immunizations. If providers identify and flag the records of children who were delayed in receiving their first vaccines beyond the age of 3 months, then >75% of those who are likely to be underimmunized at 2 years of age can be identified for extra attention. The majority of these children are only 1 visit away from being up-to-date. In the absence of complete immunization registries, using kindergarten retrospective surveys linked to census tract data can be a practical tool to assist state health departments in assessing subpopulations that can benefit from focused interventions to improve childhood immunization rates.

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