Use of Public School Immunization Data to Determine Community-Level Immunization Coverage

Enrique Ramirez, BA[a]
Igor D. Bulim, BBA[b]
John M. Kraus, BA[c]
Julie Morita, MD[a]

SYNOPSIS

Objectives. To evaluate whether immunization data collected on a child's entry into kindergarten, i.e., Chicago Public School Immunization Data (PSID), was comparable to coverage levels determined by the National Immunization Survey (NIS) and to use these data to identify community areas with consistently low immunization coverage.

Methods. The Chicago Department of Public Health obtained four years of PSID (2000–2003); these data included demographic information, home address, and immunization records. Coverage levels were determined in two ways: (*1*) one dose of measles-containing vaccine (MCV) and (*2*) four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine (the 4:3:1 series), stratified by racial/ethnic group; these levels were compared to NIS estimates for the respective time periods. We used geographic information system software to illustrate variations in coverage levels between distinct community areas within Chicago.

Results. Year 2000 MCV coverage levels determined from PSID closely approximated NIS estimates (84.6% vs. 87.2% ± 4.6%, respectively). MCV coverage levels determined by race/ethnicity from PSID were within the 95% confidence intervals (CI) for all racial categories (white, 89.5% vs. 92.2% ± 6.4%; black, 79.0% vs. 83.5% ± 9.4%; Hispanic, 89.5% vs. 87.5% ± 5.8%). Comparison of PSID and NIS 4:3:1 coverage levels revealed similar findings. For each study year, PSID identified 12 community areas with consistently low MCV coverage levels, i.e., <80%.

Conclusions. PSID closely approximated NIS coverage estimates for MCV and 4:3:1 immunization. These methods can be used by state and city health departments to identify and direct resources to communities at greatest need.

[a]Chicago Department of Public Health, Immunization Program, Chicago, IL

[b]Centers for Disease Control and Prevention, National Immunization Program, Office of Information Services and Technology, Atlanta, GA

[c]Chicago Public Schools, Office of Technology Services, Chicago, IL

Address correspondence to: Enrique Ramirez, Chicago Department of Public Health Immunization Program, 2160 West Ogden Ave., Chicago, IL 60612; tel. 312-746-5911; fax 312-746-6388; e-mail <ramirez_enrique@cdph.org>.

Childhood immunization levels are among the indicators used to assess the health of the nation. One of the *Healthy People 2010* objectives is to achieve and maintain effective vaccination coverage levels (i.e., 90%) for universally recommended childhood vaccines.[1] The National Immunization Survey (NIS) provides annual estimates of immunization coverage among children 19–35 months of age for each of the 50 states and 28 selected urban areas.[2,3] The NIS is used by many state and local health departments to guide the implementation of interventions and to measure the success of these interventions. According to the 2001 NIS, only 79% of children 19–35 months of age received their basic immunization series of four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine (4:3:1). The immunization levels in Chicago were below the national average; only 72% of children 19–35 months completed their 4:3:1 series. The 2001 NIS estimated 4:3:1 coverage for non-Hispanic black children in Chicago to be 64%, for Hispanic children to be 73% , and for non-Hispanic white children to be 82%.[4] A recent study using Chicago Public School data determined age-appropriate (7 months, 13 months, 19 months, 24 months, 36 months, 48 months, and school entry) immunization coverage levels to be low.[5] This study also demonstrated a marked racial disparity, with black children <48 months of age having the lowest coverage levels. The NIS provides coverage levels for a variety of subgroups at the national, state, and local levels. However, neither the NIS nor the previous study using Chicago Public School data provided information on how rates vary among distinct neighborhoods and communities in Chicago.

Chicago has a population of around 2.9 million people; African Americans constitute approximately 35% of the population, non-Hispanic whites 31%, and Hispanics 28%.[6] The city of Chicago spans 229 square miles along the southwestern shore of Lake Michigan and is geographically defined by 77 community areas. In 1938, a research committee at the University of Chicago divided the city into 75 community areas based upon social, cultural, and geographic factors. Since 1960, two additional community areas have been added. Demographic and health information on these 77 community areas is summarized regularly and is used by many community-based organizations, planners, hospitals, and universities. Currently, many of these community areas are racially, ethnically, and socioeconomically segregated. Improving immunization coverage in impoverished urban communities has been identified as a public health priority.[7] Identifying the community areas that have low immunization coverage levels is a critical first step in improving and sustaining adequate vaccination coverage levels.[8,9] It is also an important tool for evaluating the success of interventions that are provided to these communities.

Methods that have been used to estimate community immunization coverage include cluster surveys, school-based surveys, and provider office chart reviews.[10–13] These methodologies have been used to determine immunization coverage levels in some Chicago community areas at risk for low immunization coverage levels.[14–16] Although estimates provided by cluster and school-based surveys can provide close approximations of immunization coverage, there are limitations to these surveys. The resources required for these surveys prohibit them from being conducted frequently or in numerous communities simultaneously.[17,18] In addition, aggregation of provider chart review data in specific communities results in biased community estimates of immunization coverage because these estimates are calculated only from those children who seek medical care. Further, there are no geographic boundaries to provision of medical care.

We used immunization records collected at kindergarten entry and stored in the Chicago Public Schools health database to determine coverage levels for one dose of measles-containing vaccine (MCV) and four doses of diphtheria and tetanus toxoids and pertussis vaccine, three doses of poliovirus vaccine, and one dose of measles-containing vaccine (4:3:1 series) for children at 35 months of age. We calculated coverage levels for the 77 community areas in Chicago and mapped these levels using GIS software.[21] We validated immunization coverage levels determined using school immunization records to estimates determined by other methods, including NIS data, cluster surveys, and manual school record review.

METHODS

Public School Immunization Data (PSID)

In March 2003, a data sharing agreement was approved between the Chicago Department of Public Health and Chicago Public Schools. The Chicago Public Schools data included immunization records, demographic information, and home address for all kindergarteners enrolled during 2000, 2001, 2002, and 2003. The majority (~90%) of immunization records in the PSID originate from school physical forms authorized by a signature from either a physician or nurse. We requested the following variables: date of birth (month/year), home address, dates of immunizations required for school entry (month/year), race (self-

reported as black, white, Hispanic, Asian, or Native American), gender, and school. To prevent personal identification of children but allow for grouping of children by community area of residence, home street addresses were recoded. The last two digits of even-numbered street addresses were recoded to '00' and the last two digits of odd-numbered street addresses were recoded to '01' (i.e., 2154 changed to 2100 and 1513 changed to 1501).

To determine whether the children in the 2000 PSID database were representative of the 5-year-old population of Chicago, 2000 U.S. Census data for Chicago was compared to the PSID cohort whose birthdates fell between September 1, 1994, and August 30, 1995.

Coverage rate determination

Statistics were calculated using SAS version 8.02.[19] The population of kindergarteners was characterized by racial/ethnic group, gender, age, and the proportion of children living in each community area. CASA version 2.6 was used to calculate 4:3:1 and MCV coverage levels at 35 months of age for the total population of kindergarteners as well as for each racial/ethnic group by year and for all years combined.[20] To allow the data to be imported properly into CASA, PSID was formatted by converting four-digit birthdates and immunization dates to eight-digit dates using the 15th as the day for birthdates and immunization dates. Estimates of MCV and 4:3:1 coverage were based on the total number of doses administered on or before 35 months of age. The timeliness of vaccinations at younger ages was not evaluated in this study. To test for significant differences in immunization coverage by race/ethnicity, the Mantel-Haenszel chi-square statistic was used. To assign community areas to each address, we used the City of Chicago's Intelligent Dispatcher System, an interface operated by the Chicago Department of Business and Information Services that allows for the rapid identification of geographical areas such as ward, census tract, and community area based on street address. To illustrate the communities with consistently low immunization coverage levels, we used ArcMap version 9.0 to create a map depicting average MCV coverage levels for four years.[21]

Validation of PSID Coverage Levels

Due to the de-identification of immunization records, individual record validation was not possible. We compared our estimates from PSID to estimates determined using three separate methods. First, measles-containing vaccine (MCV) and 4:3:1 coverage levels for children aged 35 months in year 2000, estimated using 2003 PSID, were compared to 2000 National Immunization Survey estimates for Chicago. The geographic boundaries for both the NIS and PSID include Chicago city limits. NIS excludes cellular telephone exchanges from their sampling frame, sampling only land-line telephone numbers with a Chicago area code.[22] Children must have a Chicago residential address to be enrolled in a Chicago Public School. Second, the MCV coverage rate for children aged 35 months in a Chicago community in 2000, estimated using PSID, was compared to the coverage rate determined from a cluster survey conducted in the same community in 2000.[14] Third, during 2003, we reviewed a random sample of immunization records from 500 kindergarteners in six randomly selected Chicago Public Schools and compared these estimates to coverage levels determined from PSID. The randomly selected immunization records were manually entered into CASA; MCV and 4:3:1 coverage levels for each school were then compared to the school-specific coverage levels determined from the 2003 PSID.

RESULTS

Chicago Public Schools Population

The total number of kindergartener records that were available was 34,487 in 2000, 32,887 in 2001, 32,089 in 2002, and 31,950 in 2003. When analysis was limited to children 4–7 years of age with a complete home address, almost all kindergartener records (99%) were available for all four years. The racial/ethnic distribution changed very little from 2000 to 2003; the proportions of black kindergarteners were 47%, 46%, 46%, and 45%, respectively; Hispanic kindergarteners: 41%, 46%, 42%, and 42%; white kindergarteners: 9% per year; Asian kindergarteners: 3% per year; and Native American kindergarteners: <1%.

The population of kindergarteners born from September 1, 1994, to August 30, 1995, in the 2000 PSID database represented approximately 71% of the total population of 5-year-olds reported in the 2000 U.S. Census for Chicago.[6] The majority of Hispanic (82%) or non-Hispanic black (74%) 5-year-olds were represented in the PSID. However, non-Hispanic whites represented less than half (46%) of the non-Hispanic white 5-year-old population. The proportion of 5-year-olds included in PSID per community area ranged from 23%–100%. Of the 77 community areas, 56 (73%) had ≥60% of their 5-year-olds included in PSID.

Immunization coverage levels

According to PSID, MCV and 4:3:1 coverage levels for the Chicago Public Schools kindergartner population

Table 1. Annual immunization coverage levels among 35-month-olds, stratified by race. Determined using the Public School Immunization Data (PSID), 1997 through 2000, Chicago, IL

Vaccine	Year[a]	n	Total Percent (95% CI)	White Percent (95% CI)	Black Percent (95% CI)	Hispanic Percent (95% CI)
MCV[b]	1997	34,413	80.7 (80.7, 81.1)	86.8 (85.0, 86.7)	76.3 (75.8, 76.3)	84.6 (84.6, 85.0)
	1998	32,800	81.8 (81.7, 82.2)	86.9 (86.0, 87.8)	77.3 (76.7, 77.4)	85.8 (85.6, 86.0)
	1999	31,975	82.8 (82.8, 83.2)	88.7 (88.2 ,89.8)	77.0 (76.8, 77.5)	87.7 (87.6, 88.1)
	2000	31,852	84.6 (84.2, 85.2)	89.5 (89.1, 90.7)	79.0 (78.8, 79.5)	89.5 (88.7, 89.9)
	All years	131,040	82.4 (82.2, 82.6)	88.1 (87.4, 88.5)	77.5 (77.1, 77.8)	86.9 (86.6, 87.1)
4:3:1[c]	1997	34,413	65.1 (64.7, 65.2)	72.8 (71.9, 74.1)	57.2 (56.7, 57.4)	72.0 (71.7, 72.3)
	1998	32,800	67.4 (66.9, 67.4)	75.0 (73.7, 76.0)	59.2 (58.8, 59.5)	74.9 (74.6, 75.2)
	1999	31,975	68.2 (67.8, 68.3)	76.3 (74.7, 77.0)	58.9 (58.7, 59.5)	76.2 (75.6, 76.2)
	2000	31,852	70.0 (69.7, 70.3)	77.1 (75.8, 78.1)	60.6 (60.6, 61.5)	77.9 (77.6, 78.2)
	All years	131,040	67.6 (67.3, 67.8)	75.3 (74.5, 76.0)	58.9 (58.5, 59.3)	75.2 (74.9, 75.6)

[a]Three-year lag between PSID and coverage year

[b]MCV is defined as having received one dose or more of measles-containing vaccine.

[c]4:3:1 is defined as having received four or more doses of diphtheria and tetanus toxoids and pertussis vaccine, three or more doses of poliovirus vaccine, and one dose or more of measles-containing vaccine.

CI = confidence interval

at 35 months of age in Chicago were low (Table 1). Despite low coverage levels, MCV and 4:3:1 coverage levels increased from 1997–2000 (Table 1). When the four years of PSID were aggregated and coverage levels were determined by racial/ethnic group, black children residing in Chicago had significantly lower MCV coverage levels than white children (77.5% vs. 88.1%; $p<0.001$) or Hispanic children (77.5% vs. 86.9%; $p<0.001$). Black children also had significantly lower 4:3:1 coverage levels than white children (58.9% vs. 75.3%; $p<0.001$) or Hispanic children (58.9% vs. 75.2%; $p<0.001$).

Community estimates for MCV coverage were determined for the 77 community areas in Chicago from 1997–2000. The average number of records per community area used to calculate coverage rates was 1,614 records. Average coverage levels varied by community area (see Figure). Of the 77 community areas, eight community areas had an average MCV coverage level of ≥90%, 42 had an average MCV coverage level between 80%–90%, and 27 had an average MCV coverage level <80%. Twelve community areas were identified as having consistently low MCV coverage (<80%) for all four years (Figure). The racial/ethnic distribution of children (n=31,245) in these communities was 97% black, 2% Hispanic, and <1% white; whereas the racial distribution of children (n=92,917) in the remaining 65 communities was 57% Hispanic, 30% black, and 12% white. The mean percentage of the 5-year-old population represented per community area was 68%, with a range of 56%–90% in the 12 communities with consistently low MCV coverage levels and 23%–100% in the remaining 65 communities.

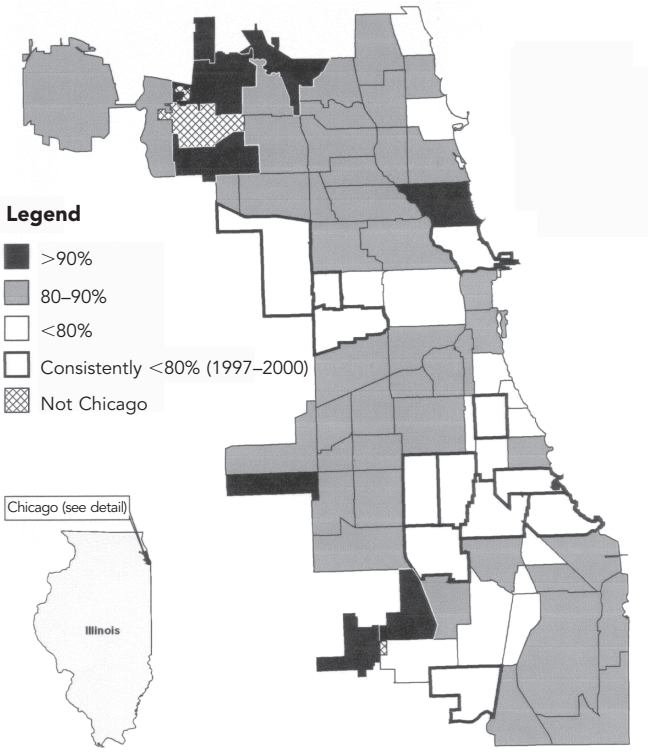
PSID validation

MCV and 4:3:1 coverage levels among 35-month-olds determined from PSID closely approximated estimates of coverage determined by the 2000 NIS for children aged 19–35 months residing in Chicago (Table 2). PSID coverage levels by racial/ethnic group were similar to NIS estimates (Table 2). In addition, all PSID coverage levels fell within the confidence intervals of the NIS estimates. Comparison of MCV and 4:3:1 coverage levels determined from PSID and manual immunization record review in six schools revealed similar coverage levels (Table 3). The confidence intervals (CI) for both coverage levels overlap, revealing no significant difference. Lastly, a comparison of MCV coverage levels for the year 2000 from a predominately African American community area determined from PSID and a cluster survey of the same community in 2000 revealed an estimate within the 95% confidence interval of the NIS estimate (71.9% [CI 68.5, 75.2] vs. 74.0% ± 5.1%).[13]

DISCUSSION

We used PSID to identify racial/ethnic groups, community areas, and schools in need of resources to address low immunization coverage levels. Importing these immunization records into CDC's CASA software allowed us to determine citywide, community

Figure. Average MCV coverage among Chicago Public Schools kindergarteners at 35 months of age for each of 77 community areas. Data aggregated for four years, 1997–2000, Chicago, IL



area, and school coverage levels quickly and efficiently. The PSID estimates for the entire city and for each racial/ethnic group were similar to those obtained from the NIS and those obtained by medical record review.

These findings suggest that immunization coverage levels determined by PSID can provide accurate estimates of immunization coverage. In addition, PSID coverage levels among Chicago's preschool population confirmed previous surveys that determined low citywide immunization coverage levels, particularly among black children.[4,14] Racial and ethnic disparities identified by PSID were also consistent with the disparities identified in a recent study examining NIS data from 1996–2001.[23] Of the twelve community areas identified as having consistently low coverage, all had large black populations (≥50%). Directing resources to these 12 communities would likely improve citywide coverage levels and decrease racial disparities in immunization coverage. Our study did not evaluate the age-appropriate administration of vaccines before 35 months of age. Dominguez et al. determined age-appropriate immunization coverage levels using Chicago Public School data.[5] They found that less than one-third of the children had received all of the recommended immunizations both at 7 and 19 months of age. In addition, black children received vaccines at a later mean age than any other racial/ethnic group. As suggested by Dominguez et al., interventions that communicate the importance of being up-to-date during the infant and toddler years are needed in black communities. Our study identified 12 communities for which this intervention is critically needed.

In the past, the Chicago Department of Public Health used community-level demographic characteristics and socioeconomic markers to identify community areas that were suspected to have low immunization coverage; household cluster surveys are too expensive and labor-intensive to use routinely for determining community-level immunization coverage levels.[18] Recently, Rosenthal and colleagues suggested using school immunization records as a practical method of determining immunization coverage levels among population subgroups or for small geographic

Table 2. MCV and 4:3:1 coverage among 35-month-olds, comparison of Public School Immunization Data (PSID) to National Immunization Survey (NIS), 2000, Chicago, IL

			Total	*White*	*Black*	*Hispanic*
Vaccine	*Source*	n	*Percent (95% CI)*	*Percent (95% CI)*	*Percent (95% CI)*	*Percent (95% CI)*
MCV[a]	PSID	31,852	84.6 (84.2, 85.2)	89.5 (89.1, 90.7)	79.0 (78.8, 79.5)	89.5 (88.7, 89.9)
	NIS	497[b]	87.2 (82.4, 91.6)	92.2 (85.6, 98.4)	83.5 (73.6, 92.4)	87.5 (82.3, 93.7)
4:3:1[c]	PSID	31,852	70.0 (69.7, 70.3)	77.1 (75.8, 78.1)	60.6 (60.6, 61.5)	77.9 (77.6, 78.2)
	NIS	497	67.2 (60.7, 73.3)	72.9 (60.2, 83.8)	60.0 (48.0, 72.0)	69.8 (61.8, 78.2)

[a]MCV is defined as having received one dose or more of measles-containing vaccine.

[b]NIS sample represents total number of children surveyed for Chicago.

[c]4:3:1 is defined as having received four or more doses of diphtheria and tetanus toxoids and pertussis vaccine, three or more doses of poliovirus vaccine, and one dose or more of measles-containing vaccine.

CI = confidence interval

Table 3. MCV[a] and 4:3:1[b] coverage among 35-month-olds, Public School Immunization Data (PSID) vs. school record review, 2003, Chicago, IL

			PSID		Record review	
School	*Enrollment[c]*	*Vaccine*	*n[d]*	*Percent (95% CI)*	*n[e]*	*Percent (95% CI)*
1	110	MCV	91	80.2 (71.9, 88.3)	25	84.0 (71.3, 96.7)
		4:3:1		63.7 (54.2, 73.9)		80.0 (66.2, 93.8)
2	180	MCV	183	89.1 (84.4, 93.5)	25	88.0 (76.1, 99.9)
		4:3:1		79.2 (73.2, 84.9)		80.0 (65.4, 94.6)
3	39	MCV	38	81.6 (68.5, 93.4)	36	77.8 (74.2, 81.8)
		4:3:1		65.8 (50.9, 81.1)		58.3 (53.5, 62.5)
4	47	MCV	51	80.4 (68.9, 90.8)	25	84.0 (74.1, 93.9)
		4:3:1		62.7 (49.9, 76.4)		68.0 (55.4, 80.6)
5	95	MCV	93	83.9 (76.4, 91.2)	26	88.5 (71.0, 96.0)
		4:3:1		64.5 (55.4, 74.7)		76.9 (57.9, 89.0)
6	29	MCV	29	79.3 (64.1, 93.7)	25	72.0 (65.3, 78.7)
		4:3:1		51.7 (34.0, 70.4)		48.0 (40.6, 55.4)

[a]MCV is defined as having received one dose or more of measles-containing vaccine.

[b]4:3:1 is defined as having received four or more doses of diphtheria and tetanus toxoids and pertussis vaccine, three or more doses of poliovirus vaccine, and one dose or more of measles-containing vaccine.

[c]Enrollment size at the time of record review in January–April, 2004

[d]Number of records represented in PSID

[e]Number of records reviewed from January to April, 2004

CI = confidence interval

areas.[18] The results of this study demonstrate that school immunization data can be used as an inexpensive, accurate, and efficient method for determining immunization coverage levels for population subgroups or small geographic areas.

If measles were introduced into any of the 12 community areas that had low MCV coverage levels (<80%) there would be a high risk for epidemic transmission.[24–26] Although measles no longer circulates in the United States, importation of measles can and does occur.[27] Results from this study will be used to guide resource allocation to these community areas at high risk for vaccine preventable diseases, and PSID can be used to monitor the success of interventions in these community areas.

As of April 2004, all 50 states in the United States, the District of Columbia, and Puerto Rico had immunization requirements for children in elementary and high school. According to the Illinois Child Health Examination Code,[28] Chicago elementary and high school students who are not in compliance with the immunization requirements can be excluded from school. Every year on October 15, Chicago Public School students who are not in compliance with immunization requirements are excluded from school. To identify those children not in compliance with the immunization requirements, Chicago Public School nurses enter immunization records into a standardized database. Obtaining a data sharing agreement for Chicago Department of Public Health to have access to the Chicago Public Schools health database was critical to the success of this project. Chicago Department of Public Health and Chicago Public Schools worked closely to define the necessary data elements and to develop methods to preserve student confidentiality while allowing Chicago Department of Public Health to determine immunization coverage levels by community area of residence. Since many school systems maintain health databases that include immunization records, it is possible that other state and local health departments may be able to use similar methods to determine immunization coverage levels for subpopulations or small geographic areas in their jurisdictions.

Immunization registries are confidential, population-based, computerized information systems that collect immunization data about all children within a geographic area.[28] Fully populated registries can consolidate immunization records of children from multiple health care providers, identify children who are due or overdue for immunizations, generate reminder and recall notices to ensure that children are immunized appropriately, and identify provider sites and geographic areas with low immunization coverage. As of 2002, 43 states in the United States and the District of Columbia reported operating registries that targeted

their entire catchment areas. Illinois has an immunization registry that targets the entire state, including Chicago. However, in 2002, the percentage of children >6 years of age with ≥2 immunizations included in the Illinois immunization registry was from 34% to 66%.[29] When a higher percentage of young children's immunization records are included in the Illinois immunization registry, the registry will be able to determine immunization coverage levels for the state and small geographic areas in Illinois. Until that time, the methods used in this study can be used to track immunization coverage levels in Chicago community areas and to assess completeness of immunization registry information.

Limitations

PSID estimates for 4:3:1 coverage may be higher than NIS estimates of 4:3:1 coverage (Table 2) because PSID coverage levels were calculated when students were 35 months of age, while NIS estimates were calculated based on the age of the child at the time of the household interview. The median age of NIS participants was 27 months.

Our estimates of immunization coverage may underestimate actual coverage. This study determined coverage levels at a specific age threshold (35 months) and did not evaluate age-appropriate immunization at younger ages. Coverage levels determined in this way have been shown to underestimate the degree of underimmunization in a population.[5,30–32]

PSID includes only immunization records of children in the public school system. Nearly 30% of five-year-olds in Chicago were not represented in PSID. Most of these children attend private schools (parochial and other private). Since children in the public school system are likely to have lower socioeconomic status than the general population and low socioeconomic status is associated with poor immunization coverage, our estimates of community immunization coverage may underestimate actual coverage. However, these data and methods are readily available and can be used to accurately identify areas with chronically low immunization coverage levels.

Another limitation of this study is that we used PSID to determine immunization coverage levels for kindergarteners when they were 35 months old. These coverage levels reflect community coverage 2–3 years prior to the year of kindergarten entry. As a result, current immunization coverage levels cannot be determined using this data. Due to this lag in coverage estimates, PSID estimates will be most useful in assessing the impact of interventions that are implemented over several years. Another possible limitation of this study is that the social, cultural, and geographic characteristics of the 77 community areas in Chicago may have changed since 1938, affecting the differences in the communities. However, since many community-based organizations and resources continue to be based on the community area structure, we chose to determine immunization coverage levels using the community area structure.

Recommendations

Using CASA to analyze PSID was an accurate and efficient method for determining immunization coverage levels for the 77 community areas in Chicago. We plan to direct resources to the 12 community areas that consistently had low immunization levels and we will use PSID to evaluate the effectiveness of our interventions. We will continue to monitor immunization coverage levels in Chicago's 77 community areas, pending more complete participation in the Illinois immunization registry. Other state or city health departments without access to a fully populated immunization registry should consider using CASA to analyze school immunization data to identify sub-populations of poorly immunized children or communities with low immunization coverage levels.

The authors thank Kevin Gibbs and Dana Harper with the Chicago Department of Public Health, Epidemiology Program, for their essential contributions to this article.

REFERENCES

1. Department of Health and Human Services (US). Healthy People 2010, 2nd edition. With understanding and improving health and objectives for improving health, 2 vols. Washington: U.S. Department of Health and Human Services; 2000.
2. Bartless DL, Ezzati-Rice TM, Stokley S, Zhao Z. Comparison of NIS and NHIS/NIPRCS vaccination coverage estimates. National Immunization Survey. National Health Interview Survey/National Immunization Provider Record Check Study. Am J Prev Med 2001;20(4 Suppl):25-7.
3. McCauley MM, Luman ET, Barker LE, Rodewald LE, Simpson DM, Szilagyi PG. The National Immunization Survey: information for action. Am J Prev Med 2001;20(4 Suppl):1-2.
4. National, state, and urban area vaccination coverage levels among children aged 19–35 months—United States, 2001. MMWR Morb Mortal Wkly Rep 2002;51(30):664-6.
5. Dominguez SR, Parrott JS, Lauderdale DS, Daum RS. On-time immunization rates among children who enter Chicago Public Schools. Pediatrics 2004;114;e741-7.
6. Census 2000 Summary File 1[cited 2004 Mar 10].Chicago: U.S. Census Bureau; c2000–. Available from: URL: http://www.census.gov
7. Recommendations regarding interventions to improve vaccination coverage in children, adolescents, and adults. Task Force on Community Preventive Services. Am J Prev Med 2000;18(1 Suppl):92-6.
8. Shefer A, Briss P, Rodewald L, Bernier R, Strikas R, Yusuf H, et al. Improving immunization coverage rates: an evidence-based review of the literature. Epidemiol Rev 1999;21:96-142.
9. Standards for pediatric immunization practices. Ad Hoc Working Group for the Development of Standards for Pediatric Immunization Practices. JAMA 1993;269:1817-22.
10. Simpson DM, Ezzati-Rice TM, Zell ER. Forty years and four surveys:

how does our measuring measure up? Am J Prev Med 2001;20(4 Suppl):6-14.
11. Rodewald LE, Roghmann KJ, Szilagyi PG, Winter NL, Campbell JR, Humiston SG. The school-based immunization survey: an inexpensive tool for measuring vaccine coverage. Am J Public Health 1993;83:1749-51.
12. Retrospective assessment of vaccination coverage among school-aged children—selected U.S. cities, 1991. MMWR Morb Mortal Wkly Rep 1992;41(06):103-7.
13. Ezzati-Rice TM, Curtin LR. Population-based surveys and their role in public health. Am J Prev Med 2001;20(4 Suppl):15-6.
14. Rosenthal J, Raymond D, Morita J, McCauley M, Diaz P, David F, Rodewald L. African-American children are at risk of a measles outbreak in an inner-city community in Chicago, 2000. Am J Prev Med 2002;23:195-9.
15. Kenyon TA, Matuck MA, Stroh G. Persistent low immunization coverage among inner-city preschool children despite access to free vaccine. Pediatrics 1998;101(4Pt1):612-6.
16. Santoli JM, Setia S, Rodewald LE, O'Mara D, Gallo B, Brink E. Immunization pockets of need: science and practice. Am J Prev Med 2000;19(3 Suppl):89-98.
17. Smith PJ, Battaglia MP, Huggins VJ, Hoaglin DC, Roden AS, Khare M, et al. Overview of the sampling design and statistical methods used in the National Immunization Survey. Am J Prev Med 2001;20(4 Suppl):17-24.
18. Rosenthal J, Rodewald L, McCauley M, Berman S, Irigoyen M, Sawyer M, et al. Immunization coverage levels among 19–35-month-old children in 4 diverse, medically underserved areas in the United States. Pediatrics 2004;113:296-302.
19. SAS Institute. SAS: version 8.2. Cary (NC): SAS Institute; 1999–2001.
20. NIP/CDC. CASA: version 2.6. Atlanta (GA): NIP/CDC; 2004.
21. ESRI Inc. ArcMap: version 9.0. Redlands (CA): ERSI, Inc; 2004.
22. Abt Associates Inc. National Immunization Survey: a user's guide for the 2000 public-use data file. Cambridge (MA): 2002. p. 8.
23. Chu SY, Barker LE, Smith PJ. Racial/ethnic disparities in preschool immunizations: United States, 1996–2001. Am J Public Health 2004;94:973-7.
24. Nokes DJ, Anderson RM. Measles, mumps, and rubella vaccine: what coverage to block transmission? Lancet 1988;2:1374.
25. Fine PE. Herd immunity: history, theory, practice. Epidemiol Rev 1993;15:265-302.
26. De Serres G, Gay NJ, Farrington CP. Epidemiology of transmissible disease after elimination. Am J Epidemiol 2000;151:1039-48.
27. Multistate investigation of measles among adoptees from China—April 9th, 2004. MMWR Morb Mortal Wkly Rep 2004;53(14):309-10.
28. Title 77: Public Health, Chapter I: Department of Public Health, Subchapter I: Maternal and Child Health, Part 665 Child Health Examination Code [cited 2004 Mar 10]. Illinois: Illinois General Assembly; c2002–. Available from: URL: http://www.ilga.gov/commission/jcar/admincode/077/07700665sections.html
29. National Vaccine Advisory Committee. Development of community and state-based immunization registries; approved January 12, 1999 [cited 2004 Mar 10]. Atlanta: U.S. Department of Health and Human Services, CDC, 1999. Available from: URL: http://www.cdc.gov/nip/registry/nvac.htm.
30. Immunization Registry Progress—United States, 2002. MMWR Morb Mortal Wkly Rep 2002;51(34):760-2.
31. Dombkowski KJ, Lantz PM, Freed GL. The need for surveillance of delay in age-appropriate immunization. Am J Prev Med 2002;23:36-42.
32. Luman ET, Barker LE, Shaw KM, McCauley MM, Buehler JW, Pickering LK. Timeliness of childhood vaccinations in the United States. JAMA 2005;293:1204-11.
33. Luman ET, McCauley MM, Stokley S, Chu SY, Pickering LK. Timeliness of childhood immunizations. Pediatrics 2002;110:935-9.