

Spatial Accessibility to Providers and Vaccination Compliance Among Children With Medicaid

AUTHORS: Linda Y. Fu, MD, MS,^{a,b} Nuala Cowan, MA,^c Rosie McLaren, MS,^d Ryan Engstrom, PhD,^c and Stephen J. Teach, MD, MPH^b

^aGoldberg Center for Community Pediatric Health and ^bCenter for Clinical and Community Research, Children's National Medical Center, Washington, DC; ^cDepartment of Geography, George Washington University, Washington, DC; and ^dNational Center for Immunization and Respiratory Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia

KEY WORDS

geography, immunizations, vaccines

ABBREVIATIONS

IIS—Immunization Information System
PCV7—7-valent pneumococcal conjugate vaccine
FTE—full-time equivalent

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Address correspondence to Linda Y. Fu, MD, MS, Goldberg Center for Community Pediatric Health, Children's National Medical Center, 111 Michigan Ave, NW, Washington, DC 20010. E-mail: lfu@cnmc.org

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WHAT'S KNOWN ON THIS SUBJECT: The geospatial availability of primary care is a known determinant of health outcomes such as asthma and mental health. State-level data have suggested this that may also be true for vaccinations.



WHAT THIS STUDY ADDS: Spatial accessibility to vaccination providers is associated with vaccination compliance among children from low-income families who live in Washington, DC.

abstract

OBJECTIVE: We examined the relationship between spatial accessibility to pediatric immunization providers and vaccination compliance in a low-income, urban population of children.

METHODS: In 2007, we accessed the Washington, DC, Immunization Information System (IIS) to collect data on the immunization statuses and residential addresses of children who were aged 19 to 35 months and had Medicaid insurance. In addition, we calculated each child's spatial accessibility to pediatric vaccination providers by assessing the provider-to-population ratio at each residential address. Spatial accessibility was divided into tertiles (low, medium, and high) of access. The relationship between spatial accessibility to providers and vaccination compliance was examined by using logistic regression analysis adjusting for age, type of vaccination provider, and enrollment in child care status.

RESULTS: Overall for our cohort of 4195 children, 80.5% of the children were up-to-date with vaccinations. Vaccination coverage ranged from 61.6% to 100% (median: 79.2%) among different neighborhoods. Having the highest level of access to pediatric vaccination providers was associated with 36% higher odds of being up-to-date as compared with having the lowest level of access. The middle tertile of access was associated with 25% higher odds of being up-to-date.

CONCLUSIONS: Within our low-income, urban population, children with higher spatial accessibility to pediatric vaccination providers were more likely to be up-to-date with vaccinations. This association may guide future studies and efforts to ensure adequate immunization coverage for children regardless of where they live. *Pediatrics* 2009; 124:1579–1586

Despite improvements in overall childhood immunization rates in the United States in the past decade, gains in certain populations have been limited. Underimmunized children are more likely to be poor,^{1,2} from single-parent households,¹ black,²⁻⁵ and from inner cities.⁶⁻⁸ These demographic characteristics also describe children who are less likely to have a regular source of primary care.⁹ The geospatial availability of primary care providers is a known determinant of health outcomes, especially for preventive services.⁹⁻¹² It is likely that lower spatial proximity to primary care providers has a disproportionate affect on at-risk, lower income populations with less access to private transportation. In surveys of at-risk populations, parents have cited transportation difficulties as a significant obstacle to having their children fully immunized.^{4,13,14} Conversely, having a provider nearby may increase adherence with medical recommendations. In a study of welfare recipients, spatial proximity to support services increased their use.¹⁵ Because children from low-income families are more likely to have parents with transportation difficulties and because they are also at higher risk for underimmunization, it is especially important to understand how spatial accessibility to primary care pediatric providers affects this population's vaccination rates. The aim of this study was to determine whether spatial accessibility to pediatric immunization providers is associated with vaccination compliance among children from low-income families in Washington, DC, as determined by Medicaid insurance enrollment.

METHODS

Vaccination Coverage

Childhood immunization rates were assessed by using the DC Department of Health Immunization Information

System (IIS), a population-based, computerized registry. The IIS consolidates vaccination data from (1) health care providers, including all providers who vaccinate children with Medicaid insurance; (2) all licensed child care providers; and (3) all DC public schools. Submission to the IIS is a requirement for Medicaid reimbursement under the Vaccines for Children Program. We extracted vaccination data on children who were aged 19 to 35 months of age as of March 1, 2007. Children were included in this study when they resided in DC, had Medicaid insurance, and, in accordance with the Centers for Disease Control and Prevention's method for assessing IIS participation rates, had at least 2 immunizations captured in the IIS.

Immunizations for each child were assessed for completion of the 4:3:1:3:3:1 combined series (≥ 4 doses of vaccine containing diphtheria and tetanus toxoids with or without pertussis; ≥ 3 doses of poliovirus vaccine; ≥ 1 dose of measles, mumps, and rubella vaccine; ≥ 3 doses of *Haemophilus influenzae* type b vaccine; ≥ 3 doses of hepatitis B vaccine; and ≥ 1 dose of varicella vaccine) and the 4:3:1:3:3:1:3 series (the 4:3:1:3:3:1 series plus ≥ 3 doses of 7-valent pneumococcal conjugate vaccine [PCV7]). Two outcomes (with and without PCV7) were chosen because vaccination with PCV7 for some of the children in our cohort may have been reduced by the national shortage that occurred from February to September 2004.¹⁶ The 4:3:1:3:3:1 and 4:3:1:3:3:1:3 series were 2 of the key series assessed by the National Immunization Survey, a population-based survey sponsored by the Centers for Disease Control and Prevention in 2007 for children aged 19 to 35 months.¹⁷

In addition to vaccination information, the following variables were extracted from the IIS: age, gender, home address, type of provider who adminis-

tered the child's last listed vaccine (public health department, federally qualified health center [ie, center receiving federal funding to care for underserved populations], other public health provider, private practice, private hospital, or other private entity) and whether the child attended a licensed child care center. It is compulsory for licensed child care centers in DC to ensure that their attendees are compliant with vaccinations and to submit documentation to the IIS. Institutional review boards at the DC Department of Health and at Children's National Medical Center approved this study.

Using ArcGIS 9.2 (ESRI Inc, Redlands, CA), we created a map of residential addresses for the children in the study, geocoded to latitude and longitude. For addresses that we were unable to geocode with the ArcGIS automated system, we manually searched and matched using GoogleMaps (www.maps.google.com) when possible. This method of interactive geocoding increases match rates and decreases the potential for selection bias as a result of incomplete geocoding.¹⁸ We included in our analysis all addresses with an ArcGIS minimum match score of 70. A perfect match yields a score of 100. The default minimum match score setting in ArcGIS is 60, but we set a higher minimum for greater confidence in address locations.

We also created a density map of our study population by using kernel estimation. Kernel density calculates the number of point features per area within each output raster cell. The output cell size is chosen by the analyst, and the final product can be represented as a smooth contour map.^{19,20} Conceptually, a smoothly curved surface is fitted over each point. The surface value is highest at the location of the point and diminishes with increasing distance from the point, reaching 0

at the search radius distance from the point. The volume under the surface equals the population field value for the point. The density of children was calculated within 0.1 mi² cells and smoothed with a Gaussian kernel density function to a distance of 1 mi. To create a ratio raster map of percentage of children who were fully immunized, we created a second density layer of all children in our study whose 4:3:1:3:3:1 vaccine series was complete, again using 0.1-mi cells and a 1-mi smoothing radius. This layer of children who had complete vaccination was divided by the layer of the entire study population to obtain a layer of percentage immunized at all points in DC. We repeated this process for 4:3:1:3:3:1:3 vaccination completion status to create a second ratio raster map.

Pediatric Vaccination Provider Spatial Accessibility

The methods for creating the provider spatial accessibility map have been described previously.^{12,19,20} Briefly, in 2004, primary care pediatric provider locations in DC were compiled from multiple sources, including the American Medical Association membership roster and practitioner lists from all DC Medicaid managed care organizations. Records were limited to pediatricians, family practitioners, and general practitioners who listed their primary activity as “direct patient care” or “resident.” Each point source of care was contacted to determine the number and type of practitioners who worked at that address, as well as the number of hours per week that each practitioner devoted to primary care services. Using guidelines from the American Academy of Pediatrics, we made adjustments for the type of training (pediatrics [weight: 1.00] versus family practice [weight: 0.75]), training level (attending [weight: 1.00] versus resident/fellow [weight: 0.35]), and type of provider (physician [weight:

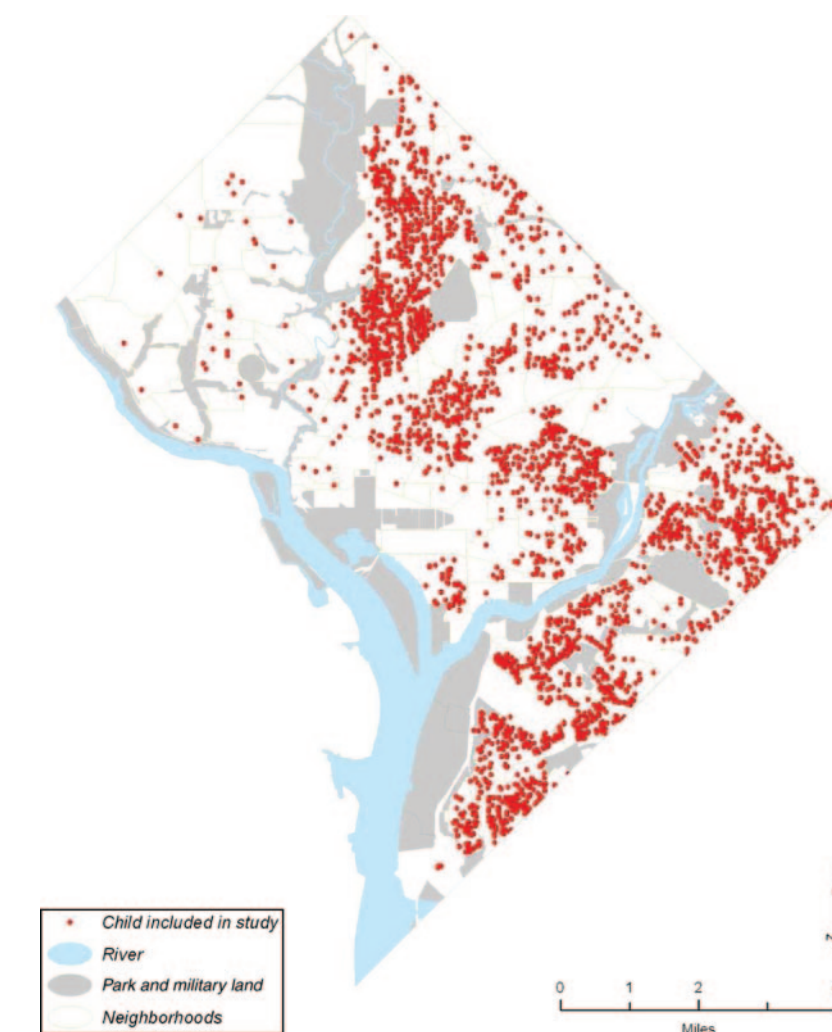


FIGURE 1 Household locations in Washington, DC, for the study population ($N = 5209$).

1.00], nurse practitioner [weight: 0.75], or physician assistant [weight: 0.75]).²¹ In addition we included 5 DC Department of Health immunization-only centers which were staffed by nurses who gave shots full-time. After comparing the average number of vaccines administered per nurse at immunization-only centers with the number of vaccines given per primary care provider at various health centers in DC, each nurse at each immunization-only center was assigned a weight of 1.00 for the hours of operation. A total number of providers who were capable of ordering/delivering vaccines was generated for each point source of care and expressed as a number of full-time

equivalent (FTE) providers on the basis of a 40-hour work week treating pediatric patients.

Spatial accessibility to vaccination providers was calculated as the ratio of pediatric provider FTEs to pediatric population.^{19,20} To do this, we created 2 density maps of DC. The provider-density layer was created using the provider (weighted by FTE) practice locations smoothed with a Gaussian kernel density function of 3 mi. The use of a 3-mi radius was based on a survey that determined the distance that black city residents typically travel to community clinics.^{12,22} The population-density layer was created from block

group centroids weighted by the number of children who were younger than 18 years and living in the block group (using 2000 US census data) and smoothed over a 1-mi radius.^{23,24} We divided the provider-density layer by the population-density layer to create a map of provider-to-population ratios. From this, we determined the ratio at the residential address of each child included in this study and defined that ratio as the child's spatial accessibility to pediatric vaccination providers.

Statistical Analysis

Means and frequencies were determined for sociodemographic and clinical characteristics of the study population. The relationship of each independent variable on the 2 outcomes, completion of the 4:3:1:3:3:1 and 4:3:1:3:3:1:3:3:1:3 vaccination series, was examined by using the χ^2 test or unpaired *t* test. A crude odds ratio with 95% confidence interval was calculated using logistic regression. To examine whether vaccination coverage varied among DC neighborhoods, we calculated vaccination rates for each of the 131 neighborhoods in DC as defined by the DC government. The median and interquartile range for vaccination rate by neighborhood was determined for the 80 neighborhoods with ≥ 10 study children.

To examine vaccine completion rates as a function of spatial accessibility to providers, we created 2 multivariate logistic regression models. The spatial accessibility measure was divided into tertiles for ease of interpretation of the results (low, medium, and high accessibility). Because we were examining spatial accessibility for DC, a jurisdiction of only 61 mi², we believed that greater partitioning of the spatial accessibility variable into more categories (or examining it as a continuous variable) would be misleading. The outcomes of interest for the 2 models

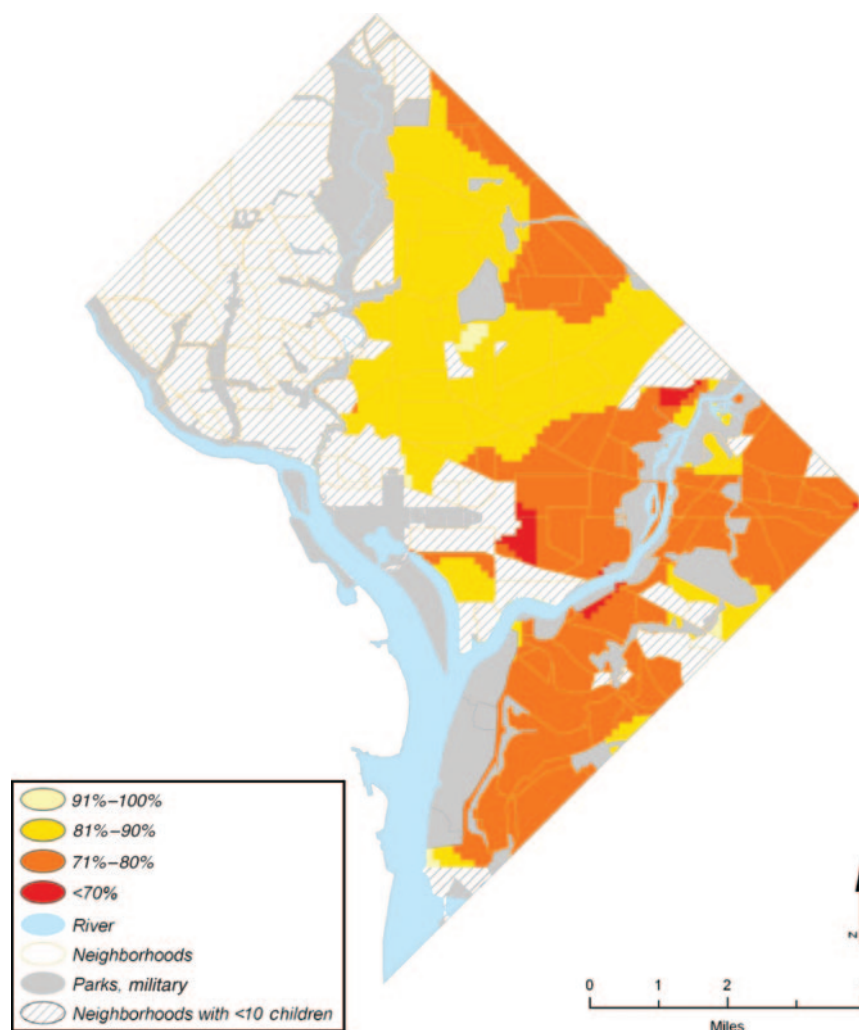


FIGURE 2 Percentage of the study population who had completed the 4:3:1:3:3:1 vaccination series in Washington, DC.

were completion of the 4:3:1:3:3:1 and 4:3:1:3:3:1:3:3:1 vaccination series, respectively. Each model was adjusted for age, type of vaccination provider, and enrollment in child care status. These variables were checked for correlation with each other and the spatial accessibility variable by using Pearson correlation coefficients, which ranged from 0 to 0.27 for all pairings. Because of a relatively high percentage of missing values for the variable type of vaccination provider (3.6%), we created a dummy variable for both models for the missing values of this variable. The Hosmer and Lemeshow goodness-of-fit test was used to deter-

mine the fit of the models to the data. All analyses were conducted by using SAS 9.2 (SAS Institute, Inc, Cary, NC). Test levels for significance were $P < .05$.

RESULTS

As of March 1, 2007, 5310 children 19 to 35 months of age with Medicaid insurance had ≥ 2 vaccinations listed in the DC IIS. Of these, 101 (1.9%) were excluded from analysis because they had addresses of record that we were unable to convert to latitudinal and longitudinal positions for 1 of the following reasons: mapped to a nonresidential site, contained a nonexistent street

number or name, or lacked critical street information so that the address could not be identified as a single, discrete location. The rest of the sample ($n = 5209$) had addresses that we were able to convert to ordinal positions and were included in the analysis (Fig 1). As is seen in Fig 1, the vast majority of our study population resided in the northeast and southeast quadrants of DC.

Overall, for our cohort, 4195 (80.5%) children were complete for the 4:3:1:3:3:1 vaccination series and 3508 (67.3%) children were complete for the 4:3:1:3:3:1:3 series. Vaccination coverage rates varied greatly across the city (Fig 2). Among neighborhoods with ≥ 10 study children, vaccine completion rates for the 4:3:1:3:3:1 series ranged from 61.6% to 100% (median: 79.2% [interquartile range: 75.0%–84.4%]) and 41.7% to 94.5% (median: 76.9% [interquartile range: 70.0%–81.7%]) for the 4:3:1:3:3:1:3 series.

The density of pediatric providers as compared with pediatric population also varied across the city (Fig 3). Almost uniformly, the more socioeconomically advantaged northwest quadrant had the highest category of concentration of providers (>90 providers per 100 000 children). By contrast, coverage of the more socioeconomically disadvantaged southeast quadrant²⁵ dipped to ≤ 30 providers per 100 000 children in 1 large area.

Before adjustment, completion of both the 4:3:1:3:3:1 and 4:3:1:3:3:1:3 vaccination series was related to multiple factors examined (Tables 1 and 2). As expected, older age was associated with vaccination completion. Each 1-month increment in age was associated with an 8% increase in odds of 4:3:1:3:3:1 vaccination series completion and a 6% increase in odds of 4:3:1:3:3:1:3 completion. Child care attendance was strongly associated with compliance

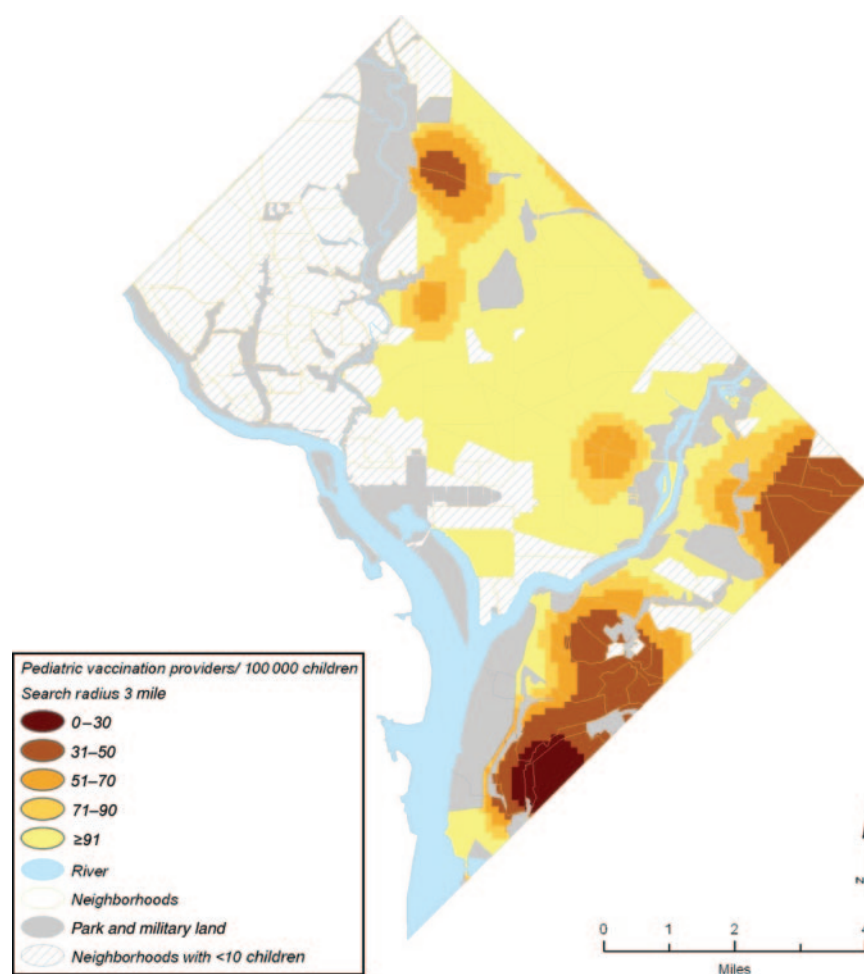


FIGURE 3
Distribution of pediatric vaccination providers (in terms of FTEs) in Washington, DC.

with vaccinations: those who attended child care had >8 times higher odds of 4:3:1:3:3:1 series completion and almost 4 times the odds of 4:3:1:3:3:1:3 series completion. The type of vaccination provider was also significant. Receiving immunizations from a federally qualified health center, another type of public health provider, a private hospital, or other private entity was associated with vaccination completion, compared with receiving vaccinations from a private practitioner, although private practitioners as a group cared for almost half (46.0%) of the study population. Finally, higher spatial accessibility to vaccination providers was associated with vaccination completion. Children who were in the high-

est tertile of spatial accessibility had 1.42 higher odds of being 4:3:1:3:3:1 series complete and 1.33 higher odds of being 4:3:1:3:3:1:3 series complete as compared with the lowest tertile. Also increased odds of vaccination completion were associated with the middle versus the lowest tertile of spatial accessibility (1.28 and 1.18 for the 2 respective series).

The relationship between spatial accessibility to pediatric vaccination providers and vaccination compliance was additionally examined after adjustment for age, type of vaccination provider, and enrollment in child care status (Table 3). After adjustment, having the highest access to providers

TABLE 1 Characteristics of Study Population as Related to Completion of the 4:3:1:3:3:1 Vaccination Series (N = 5209)

Variable	Series Incomplete (n = 1014)	Series Complete (n = 4195)	Unadjusted OR (95% CI) for Series Completion
Age, mean ± SD, mo	25.7 ± 5.0	27.6 ± 4.8	1.08 (1.07–1.10) ^a
Gender, %			
Female	48.7	49.4	1.03 (0.90–1.18)
Male	51.3	50.6	Reference
Type of immunization provider, % ^b			
Private hospital or other private entity	13.9	20.4	1.80 (1.47–2.21)
DC Department of Health vaccination-only clinic	3.9	1.7	0.55 (0.37–0.83)
Federally qualified health center	19.0	25.0	1.61 (1.34–1.94)
Other public health provider	9.0	8.8	1.21 (0.94–1.56)
Private practice	54.2	44.1	Reference
Enrolled in licensed child care, %			
Yes	2.5	17.0	8.06 (5.41–12.05)
No	97.5	83.0	Reference
Tertile of spatial accessibility of vaccination providers, %			
Highest	29.3	34.4	1.42 (1.20–1.68)
Middle	31.3	33.1	1.28 (1.09–1.51)
Lowest	39.4	32.5	Reference

OR indicates odds ratio; CI, confidence interval; SD, standard deviation.

^a Odds reported for each 1-month increase in age.

^b Missing 187 responses.

TABLE 2 Characteristics of Study Population as Related to Completion of the 4:3:1:3:3:1:3 Vaccination Series (N = 5209)

Variable	Series Incomplete (n = 1153)	Series Complete (n = 4056)	Unadjusted OR (95% CI) for Series Completion
Age, mean ± SD, mo	26.1 ± 5.1	27.7 ± 4.8	1.06 (1.05–1.07) ^a
Gender, %			
Female	49.0	49.3	1.01 (0.89–1.16)
Male	51.0	50.7	Reference
Type of immunization provider, % ^b			
Private hospital or other private entity	13.9	20.4	2.01 (1.65–2.45)
DC Department of Health vaccination-only clinic	3.9	1.7	0.49 (0.33–0.72)
Federally qualified health center	19.0	25.0	1.81 (1.52–2.17)
Other public health provider	9.0	8.8	1.35 (1.06–1.73)
Private practice	54.2	44.1	Reference
Enrolled in licensed child care, %			
Yes	5.1	16.7	3.72 (2.82–4.90)
No	94.9	83.3	Reference
Tertile of spatial accessibility of vaccination providers, %			
Highest	29.9	34.4	1.33 (1.13–1.56)
Middle	32.2	32.9	1.18 (1.01–1.39)
Lowest	37.9	32.7	Reference

OR indicates odds ratio; CI, confidence interval; SD, standard deviation.

^a Odds reported for each 1-month increase in age.

^b Missing 187 responses.

was associated with 1.36 higher odds of being 4:3:1:3:3:1 series complete and 1.23 higher odds of being 4:3:1:3:3:1:3 series complete. The middle tertile of

access was associated with 1.25 and 1.11 higher odds of being complete for the 4:3:1:3:3:1 and 4:3:1:3:3:1:3 series, respectively, although the relationship

TABLE 3 Vaccine Series Completion as Related to Tertile of Spatial Accessibility of Vaccination Providers

Tertile of Spatial Accessibility of Vaccination Providers	Adjusted OR (95% CI) for 4:3:1:3:3:1 Series Completion ^a	Adjusted OR (95% CI) for 4:3:1:3:3:1:3 Series Completion ^a
Highest	1.36 (1.14–1.62)	1.23 (1.04–1.45)
Middle	1.25 (1.05–1.49)	1.11 (0.94–1.31)
Lowest	Reference	Reference

Odds ratios (ORs) are adjusted for age, type of vaccination provider, and enrollment in child care status. CI indicates confidence interval.

was significant only for the 4:3:1:3:3:1 series.

DISCUSSION

We found that with increasing spatial accessibility, the odds of vaccination completion are also increased even after adjustment for age, type of vaccination provider, and enrollment in child care. This study enhances the growing evidence that geographic availability of providers is important for a wide range of conditions best managed by iterative, longitudinal health care, including asthma,¹² prenatal care,²⁶ and mental health.¹⁵

Immunization rates for our study population for the 4:3:1:3:3:1 and 4:3:1:3:3:1:3 series (80.5% and 67.3%, respectively) were similar to but slightly lower than the 2007 coverage rates in DC reported by the National Immunization Survey (81.6% and 77.3%, respectively).¹⁷ We expected coverage rates for children in our study to be slightly lower, because we included only children from lower income families.

In our study, some neighborhoods had a much lower rate of vaccination compliance than others; vaccination compliance rates varied 38.4% among neighborhoods for the 4:3:1:3:3:1 series and 52.8% for the 4:3:1:3:3:1:3 series. Characteristics such as predominant languages spoken and cultural norms may differ between people who

live in adjacent but distinct neighborhoods. The ability to identify at the neighborhood level areas with low vaccination coverage may facilitate tailoring interventions to the specific needs of a neighborhood. It may also guide governmental allocation of limited resources to neighborhoods where immunization improvement is needed most.

The results of our study may enhance understanding of a study by LeBaron et al,²⁷ who found that, overall, a higher ratio of pediatricians to infants in a state was associated with higher state vaccination coverage rates; however, DC had the highest density of pediatricians in the nation and a vaccination coverage rate below the median. A possible explanation is that there is greater socioeconomic heterogeneity in DC than in other states. DC has more children living in poverty than the national average, but the median income is also higher than average.²⁸ In our study, which was limited to low-income families, pediatric provider distribution was associated with vaccination coverage rates.

Our results contrast with previous findings of Baumgardner et al,²⁹ who found no association in a population of 151 predominantly low-income children between travel distance to a medical clinic and vaccination compliance. The contrast in findings might be explained by differences in methods. Our study looked at spatial accessibility to all vaccination providers in DC, rather than just to 1 site. This may be an essential difference if families with significant transportation barriers tend to choose health care providers who

are closest to their homes, because it is unknown whether the clinic in the study by Baumgardner et al was the nearest center for children in that study. Families who were involved in the study by Baumgardner et al may have bypassed closer providers because of language barriers: 85% of their clinic population was Hispanic. Our study was likely composed predominately of black children, because our population was limited to Medicaid recipients and 97% of all children who received welfare in DC in 2007 were black.³⁰

Characteristics of a vaccination provider in addition to geographic proximity affect access to care and vaccination compliance. Access to a source of pediatric care may be reduced by language barriers, difficulties making appointments,^{4,14} long waiting times,¹⁴ and lack of after-hours services.¹⁰ In addition, the provider's use of reminder/recall systems and other immunization best practices influences the likelihood that vaccinations are delivered appropriately.³¹ In our study, there was an association between type of vaccination provider and vaccination compliance. If these nonspatial factors related to access differ on the whole between various types of providers, then it might explain the relationship between vaccination provider type and immunization compliance that we found.

We reported our analysis assuming that families would travel up to 3 mi for vaccines. Of note, the results of analysis that used a 2-mi radius were essentially the same (not reported). Our study population was intentionally lim-

ited to urban, low-income children because poverty and living in a city both are risk factors for noncompliance with vaccinations.^{1,2,6,8} Our results, therefore, should not be extrapolated to higher income, suburban or rural families, who may travel farther for pediatric health care services.

Because our data are cross-sectional, causality cannot be determined. A next step would be to compare perceptions about the role of transportation difficulties in vaccination noncompliance among residents of neighborhoods with similar socioeconomic and demographic characteristics but different spatial accessibility to providers.

CONCLUSIONS

Our study demonstrated that increased spatial proximity to pediatric vaccination providers was positively associated with vaccination completion rates among Medicaid recipients in Washington, DC. This association may guide future studies and efforts to ensure immunization coverage of children regardless of where they live. Such interventions may need to find ways to increase transportation options for low-income families to reach providers or to incentivize more providers to practice in underserved areas.

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