HHS Public Access
Author manuscript
Birth Defects Res. Author manuscript; available in PMC 2018 November 01.

Published in final edited form as:
Birth Defects Res. 2017 November 01; 109(18): 1494–1503. doi:10.1002/bdr2.1129.

Proximity to Pediatric Cardiac Surgical Care among Adolescents with Congenital Heart Defects in 11 New York Counties

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Abstract

Background—Many individuals with congenital heart defects (CHDs) discontinue cardiac care in adolescence, putting them at risk of adverse health outcomes. Because geographic barriers may contribute to cessation of care, we sought to characterize geographic access to comprehensive cardiac care among adolescents with CHDs.

Methods—Using a population-based, 11-county surveillance system of CHDs in New York, we characterized proximity to the nearest pediatric cardiac surgical care center among adolescents aged 11 to 19 years with CHDs. Residential addresses were extracted from surveillance records documenting 2008 to 2010 healthcare encounters. Addresses were geocoded using ArcGIS and the New York State Street and Address Maintenance Program, a statewide address point database. One-way drive and public transit time from residence to nearest center were calculated using R packages *gmapsdistance* and *rgeos* with the Google Maps Distance Matrix application programming interface. A marginal model was constructed to identify predictors associated with one-way travel time.

Results—We identified 2522 adolescents with 3058 corresponding residential addresses and 12 pediatric cardiac surgical care centers. The median drive time from residence to nearest center was 18.3 min, and drive time was 30 min or less for 2475 (80.9%) addresses. Predicted drive time was

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Additional Supporting information may be found in the online version of this article.

Conflict of interest: The authors declare that there is no conflict of interest.

longest for rural western addresses in high poverty census tracts (68.7 min). Public transit was available for most residences in urban areas but for few in rural areas.

Conclusion—We identified areas with geographic barriers to surgical care. Future research is needed to determine how these barriers influence continuity of care among adolescents with CHDs.

Keywords

heath care accessibility; travel time; GIS; congenital heart defects; pediatric cardiac surgery

Introduction

Today it is estimated that 2.4 million people in the United States are living with congenital heart defects (CHDs) (Gilboa et al., 2016). Per American College of Cardiology/American Heart Association guidelines for adult congenital heart disease (ACHD), regular cardiac follow-up care is recommended for individuals living with CHDs (Warnes et al., 2008). Additionally, recent research highlights the importance of structured transitional programs for adolescents with CHDs as they move to adult-centered care (Dore et al., 2002; Moons et al., 2008; Sable et al., 2011). Despite this, more than half of adolescents with CHDs become lost to cardiac follow-up before they reach 20 years of age (Goossens et al., 2011; Gurvitz et al., 2013). Discontinuation of care has been linked to adverse health outcomes in this population, including an increased risk for presentation in emergency care (Yeung et al., 2008). It is, therefore, critical to evaluate the factors associated with appropriate healthcare usage among adolescents with CHDs.

Healthcare usage is driven in part by enabling factors, the logistical aspects of accessing care (Andersen, 1995). Prior research has demonstrated that differences in travel distance to appropriate care among individuals with birth defects can have a significant impact on healthcare use, and it has been suggested that geographic barriers may play a role in cessation of care among those with CHDs (Cassell et al., 2013; Gurvitz et al., 2013). Despite these findings, research characterizing geographic access to appropriate care among individuals with CHDs has been limited. One study estimated the mean population-weighted straight line distance from zip code centroid to pediatric cardiology provider to be 22 miles, but there has been no research using individual-level address data to estimate proximity to specialty care (Mayer, 2006).

It is useful to consider measures of proximity that appropriately reflect the modes of transportation used by the population of interest. Drive time may be the preferred proximity measure in peripheral and rural areas because personal vehicle use is ubiquitous, but public transit time may be a better measure of access in large cities where vehicle ownership is less common, such as New York City (Pucher and Renne, 2005). Studies that fail to incorporate both drive time and public transit time may not accurately capture barriers in access to adequate care. To our knowledge, public transit has not been examined in any health-care proximity analysis among individuals with birth defects.

There is limited information regarding proximity to specialty care centers among adolescents with CHDs, a population at high risk for discontinuation of care. To characterize geographic access to comprehensive cardiac care among adolescents with CHDs, we used a Geographic Information Systems (GIS)/Google Maps Application Programming Interface (API)-based network analysis to examine drive time, public transit availability, and public transit time from residential address to the nearest pediatric cardiac surgical care center for adolescents with CHDs in 11 New York counties. We also explored associations between selected sociodemographic, census tract and clinical factors and drive times.

Materials and Methods

POPULATION

We conducted an analysis examining proximity to pediatric cardiac surgical care among adolescents (ages 11 to 19 years as of January 1, 2010) with CHDs who resided in select western (Allegany, Cattaraugus, Chautauqua, Erie, Genesee, Monroe, Niagara, Orleans, Wyoming) and southeastern (Bronx or Westchester) counties in New York State between January 1, 2008 and December 31, 2010.

We used data from a newly developed surveillance database of CHDs in New York State ("Surveillance of Congenital Heart Defects Focusing on Adolescents and Adults" project-CDC-RFA-DD12-1207). This population-based database was developed by the New York State Department of Health in collaboration with researchers and clinicians affiliated with the Centers for Disease Control and Prevention, Emory University and the Massachusetts Department of Public Health to improve understanding of the epidemiology and public health significance of CHDs, particularly regarding prevalence, survival outcomes, and barriers to effective care. It incorporates hospital inpatient, outpatient and emergency department records from the Statewide Planning and Research Cooperative System (SPARCS), an all-payer data reporting system in New York, as well as healthcare encounter records from seven pediatric cardiology clinics in the 11-county surveillance region. Surveillance system records captured patient addresses, sociodemographic characteristics, diagnoses, treatments, services and charges for healthcare encounters occurring between January 1, 2008, and December 31, 2010.

An adolescent was considered a CHD case if he or she had documentation of one or more of the following International Classification of Diseases, 9th revision, Clinical Modification (ICD-9-CM) codes: 745.XX-747.XX, excluding 746.86 (congenital heart block), 747.32 (pulmonary arteriovenous malformation), 747.5 (absence or hypoplasia of umbilical artery), 747.6 (other anomalies of peripheral vascular system), and 747.8 (other specified anomalies of the circulatory system) in one or more of the surveillance system data sources.

VARIABLES

Residential addresses—We captured residential addresses for adolescents with CHDs from all healthcare encounter records within the study period. We excluded records with residential addresses outside of the 11-county surveillance region as well as records with hospital addresses listed as residential addresses.

Pediatric cardiac surgical care centers—Because multidisciplinary care is often recommended for individuals with CHDs due to their complex healthcare needs, we sought to determine proximity to centers equipped to offer comprehensive care of CHDs, including advanced imaging, cardiac catheterization and electrophysiology in addition to cardiac surgery (Foster et al., 2001). We treated centers licensed to perform pediatric cardiac surgery as an imperfect proxy for CHD specialty care centers because a definitive list of CHD specialty care centers does not exist. Pediatric cardiac surgical care centers were defined as any facility approved to offer pediatric congenital cardiac surgery between 2006 and 2009 (New York State Department of Health Cardiac Services Program, 2011). These centers were listed in a 2011 report developed by the New York State Department of Health Cardiac Services Program with the help of the New York State Cardiac Advisory Board to resolve the challenges involved in evaluating cardiac surgery data due to the wide ranges of diagnoses and procedures involved. We validated this definition for our study period by assessing the percent of cardiac procedures conducted at licensed and unlicensed facilities in the state using SPARCS hospital inpatient records. The 12 facilities licensed to offer pediatric congenital cardiac surgery performed 97% of all adolescent cardiac surgical procedures in New York from 2008 to 2010.

Residential addresses and pediatric cardiac surgical care center addresses were geocoded using ArcGIS and the New York State Street and Address Maintenance Program (SAM), a statewide address point database.

Individual-level variables—Individual-level variables included age (as of January 1, 2010), sex and CHD severity. As part of the “Surveillance of Congenital Heart Defects Focusing on Adolescents and Adults” project, cases were categorized as severe (requiring surgical or catheter intervention in the first year of life) or nonsevere using ICD-9-CM diagnosis codes aggregated from all surveillance system records. Each ICD-9-CM CHD code was designated as severe or nonsevere by cardiac clinicians as a component of surveillance system development with consideration given to basic anatomy and hemodynamic severity. If a case had at least one severe ICD-9-CM diagnosis code, that case was classified as severe. Otherwise, a case was classified as nonsevere. Table A1 in the Supplementary Appendix, which is available online, contains the ICD-9-CM codes comprising the severe and nonsevere categories.

Census tract-level variables—Census tracts corresponding to the geocoded residential addresses for each case were identified using 2010 US Census boundary data. The 2010 Census, 2010 Rural-Urban Commuting Area (RUCA) codes and the 2008 to 2012 American Community Survey were used to determine census tract minority composition, rurality, and poverty (United States Census Bureau, 2010; 2013; United States Department of Agriculture, 2013). The 2010 Census provided racial and ethnic composition information for each census tract. We calculated the percent minority (non-white and/or Hispanic) composition for each census tract and then dichotomized the variable into low minority census tracts (>50% of the population were non-Hispanic white) and high minority census tracts (≤50% of the population were non-Hispanic white).

We matched each census tract within our surveillance region to its corresponding 2010 Rural-Urban Commuting Area (RUCA) code, which classifies a census tract based on its population density, urbanization and daily commuting. Each census tract was then designated as either rural or urban based on the Categorization C RUCA classification scheme (WWAMI Rural Health Research Center, 2005). Figure 1 illustrates the surveillance region with assigned rural/urban categorizations for census tracts. We used the 2008 to 2012 American Community Survey to calculate the percent of the population living at or under the federal poverty level (FPL) for each census tract and, based on the Census Bureau definition, dichotomized census tracts as low poverty areas (<20% of the population living at or under the FPL) and high poverty areas (≤20% of the population at or under the FPL).

Region-rurality variable—We sought to characterize time to care from residential addresses in rural census tracts and residential addresses in urban census tracts separately within each region (southeastern or western New York). The southeastern New York surveillance region includes Bronx County and Westchester County, located within and directly north of New York City, respectively, with a combined population of over 2 million people (United States Census Bureau, 2010). Because there were only two rural census tracts in this two-county region, we did not draw a distinction between addresses in rural and urban census tracts in the southeastern region.

Although the nine western New York counties include the cities of Buffalo, Rochester, and Niagara Falls, there are many rural census tracts in this region as well. To capture this heterogeneity, residential addresses in western New York were categorized as urban or rural using the census tract assignment variable described in the previous section. Our region-rurality variable ultimately contained categories for southeastern New York, urban western New York, and rural western New York.

Outcome variables: One-way drive time and one-way public transit time—The primary outcome of interest in this analysis was the one-way drive time (in minutes) from residential address to nearest pediatric cardiac surgical care center for adolescents with CHDs. A secondary outcome of interest was the public transit time (in minutes) from residential address to nearest pediatric cardiac surgical care center.

A distance matrix for the minimum Cartesian distance was first calculated to identify the three closest facilities for an individual's address at each encounter using the *rgeos* package in R (version 0.3-22, Bivand et al., 2016). We then used the *gmapsdistance* package in R to access the Google Maps Distance Matrix API by means of Hypertext Transfer Protocol Secure (HTTPS) and calculated drive distance, drive time, and transit time from each identified residential address to each of the three centers nearest to that address (version 3.1, Melo and Zarruk, 2016). In each iteration, travel time was estimated between one origin and one destination by calling the Google Distance API. The iterations stopped when the program reached the last combination of origins and destinations. To maintain confidentiality, geographic coordinates of the residential and pediatric cardiac surgical center addresses were to the API without any accompanying information.

The Google API retrieves distances and times based on the date and time of query. We limited the queries to the morning and early afternoon (9 AM through 2 PM) to reflect travel times expected for day-time surgical center visits given traffic patterns and public transit availability. Transit data are available for major metro areas in New York State through Google API. Public Transit calculations were thus limited to only those areas where this information was available.

STATISTICAL ANALYSIS

We calculated summary statistics for one-way drive time and one-way public transit time overall and stratified by region-rurality and county. To determine whether selected factors were associated with one-way drive time, we constructed a marginal linear model using generalized estimating equations (GEE) with robust standard errors and an exchangeable correlation structure. GEEs were used to control for within-person correlation between multiple address records reported for the same individual. Multiple imputation by fully conditional specification was used to handle missing values for sex, missing for 10% of cases. There was a high degree of collinearity between urban-rural classification and minority status. In our surveillance area, most addresses in high-minority tracts (99.8%) were in urban areas. We, therefore, excluded the minority area variable from further analysis. All other selected individual and census-tract level variables were included in the final model. Age was centered at 11 because our analysis targeted 11 to 19-year-olds.

All GIS and statistical analyses were performed using ArcGIS 10.3, R 3.3.2, SAS 9.3 (SAS Institute Inc, Cary, NC) and STATA (Version 13, StataCorp, College Station, TX). This analysis was approved by the institutional review boards of the New York State Department of Health.

Results

We identified 2522 adolescent CHD cases with 3058 corresponding unique residential addresses from 2008 to 2010. There was one address reported for 2114 cases and two or more addresses reported for 408 cases (range: one to eight addresses per case). Address-level geocoding using was successfully performed for 2918 (95.4%) residential addresses using SAM. Zip code-centroid geocoding was performed for the remaining 140 addresses. All 12 pediatric cardiac surgical care centers were successfully geo-coded at the address level.

CASE AND RESIDENTIAL ADDRESS CHARACTERISTICS

Table 1 summarizes characteristics for the 2522 cases in our analysis, and Table 2 summarizes characteristics for the 3058 residential addresses reported for adolescent cases between 2008 and 2010. Approximately 20% of cases were categorized as having severe CHDs ($n = 515$). We were missing information on sex for 10% ($n = 252$) of cases. Over half ($n = 1576$; 51.5%) of identified addresses were in urban western New York, and most addresses were in low poverty area census tracts ($n = 2032$; 66.5%).

OBSERVED ONE-WAY DRIVE TIMES AND ONE-WAY PUBLIC TRANSIT TIMES

Table 3 summarizes one-way drive times and one-way public transit times from residential addresses to nearest pediatric cardiac surgical care center. Overall median one-way drive time was 18.3 min (interquartile range [IQR]: 14.1–26.6), and one-way drive time was 30 min or less for 2475 (80.9%) addresses. Stratifying by regionrurality, median drive time in southeastern New York was 15.1 min (IQR: 12.6–18.1), compared with 21.0 min (IQR: 15.8–27.8) in urban western New York and 63.2 min (IQR: 51.8–89.1) in rural western New York.

Drive time to nearest pediatric cardiac surgical care center was 30 min or less for nearly all southeastern New York addresses, compared with approximately 81% (*n* = 1283) of urban western New York addresses and <1% (*n* = 2) of rural western New York addresses. In rural western New York, approximately 24% (*n* = 67) of addresses were more than a 90-min drive away from the nearest pediatric cardiac surgical care center. In contrast, there were no addresses more than a 90-min drive to surgical care in either urban western New York or in southeastern New York. Drive time patterns for the southeastern and western New York surveillance regions are illustrated in the Supplementary Appendix (Figs. A1 and A2).

Public transit to a surgical care center was available for 2301 (75.2%) of the 3058 addresses in our dataset. Public transit coverage in southeastern New York was 87.7%, compared with 78.9% in urban western New York and 2.1% in rural western New York. In 6 of the 11 counties in the surveillance region, public transit options were available to less than 10% of the population.

In all regions, median drive time to nearest pediatric cardiac surgical care center was less than the median public transit time for residential addresses with public transit available. Overall, median one-way drive time was 16.3 min (IQR: 13.3–21.0) and median one-way public transit time was 53.1 min (IQR: 33.3–76.3). The difference between median drive time and median public transit time was smallest in southeastern New York (14.8 min vs. 39.6 min) and greatest in rural western New York (51.2 min vs. 324.9 min). Public transit patterns are shown in the Supplementary Appendix (Figs. A3 and A4).

PREDICTORS OF ONE-WAY DRIVE TIME

We found significant interaction between region-rurality and census tract poverty in our multivariate analysis of one-way drive time predictors (Table 4). Other factors such as age, sex and CHD severity were not significant predictors in our analysis. Predicted one-way drive times were calculated to explore the interaction between region-rurality and census tract poverty. Table 5 presents these times for different levels of region-rurality and census tract poverty at the reference levels of all other variables in the model. The predicted one way-drive time was shortest for addresses in poverty areas in southeastern New York (14.3 min) and longest for addresses in poverty areas in rural western New York (68.7 min). The difference in drive times between high poverty and low poverty areas was greatest in the urban western New York region (16.7 min and 24.3 min, respectively).

Discussion

Research has increasingly focused on geographic access to care among individuals with birth defects (Case et al., 2008; Fixler et al., 2012; Cassell et al., 2013; Delmelle et al., 2013; Radcliff et al., 2015). We characterized one-way drive time, one-way public transit time, and public transit availability to pediatric cardiac surgical care centers in New York for adolescents with CHDs. We also examined individual, census-tract, and region-level factors associated with drive time to surgical care using multivariate linear regression. Although most adolescent residential addresses were within a 30-min drive to this type of care, one-way drive time to a surgical care center was 90 min or more for almost a quarter of addresses in rural western New York. In multivariate modeling, the low predicted drive times for addresses in urban census tracts and high predicted drive times for addresses in rural census tracts reflected the urban location of pediatric cardiac surgical care centers in the state.

Census tract poverty was found to be a significant predictor of one-way drive time to pediatric cardiac surgical care. In our surveillance region, many surgical care facilities were in high-density urban areas characterized by high poverty, including Rochester and the Bronx. Drive time to care in urban areas was slightly lower for addresses in high poverty census tracts than for addresses in low poverty census tracts. In contrast, drive times for addresses in high poverty census tracts were higher than those in low poverty areas in rural western New York, but this difference was not statistically significant. Rural western New York addresses in both high and low poverty census tracts had predicted drive times to surgical care greater than an hour.

Our project is one of the first to examine public transit availability and public transit time to care among individuals with birth defects, addressing a common limitation of similar work (Delmelle et al., 2013; Radcliff et al., 2015). Mirroring drive time patterns, public transit to surgical care was available for most identified addresses in urban regions but for very few addresses in rural western New York. Although median public transit time was greater than median drive time in all areas, the difference between public transit time and drive time was greatest for addresses in rural western New York census tracts. Rural western New York was identified as an area with geographic barriers to surgical care access for adolescents with CHDs, including high one-way drive times, limited public transit availability, and high public transit times.

Our findings are generally consistent with prior work indicating that differences in geographic access to care exist among individuals with birth defects (Case et al., 2008; Delmelle et al., 2013). The association between rural residence and increased travel time to appropriate care among those with birth defects, for example, has been well documented (Delmelle et al., 2013; Radcliff et al., 2015). In contrast to prior work, we found no association between defect severity and proximity to care (Cassell et al., 2013; Radcliff et al., 2015). This difference may be explained in part by choosing to target those who had survived into adolescence rather than infants. Over half of deaths caused by CHDs occur within the first 4 years of life, after which mortality drops significantly (Gilboa et al., 2010). Any relationship that may exist between CHD severity and proximity to surgical care may have been blunted by targeting those healthy enough to survive past infancy and early childhood.

Our analysis has several limitations. First, we chose to characterize access to pediatric cardiac surgical care centers because a comprehensive list of CHD specialty care centers in New York State does not exist. Because many adolescents may not necessarily require surgical intervention, our definition of specialty care may have been more restrictive than necessary (Warnes et al., 2008; Jacobs et al., 2014). If we expanded our definition to include facilities where any type of CHD-related care is offered, such as smaller pediatric cardiology clinics and specialist outreach clinics, we expect that travel time patterns might differ from what we have presented here, particularly in rural areas. Future work would benefit from incorporating centers offering different types of pediatric cardiology care.

As a second limitation, we restricted surgical care centers to those located in New York State, ignoring proximity to centers located in bordering states where patients may have chosen to seek surgical care. Proximity estimations should be interpreted keeping this in mind. Third, we chose to characterize proximity to surgical centers identified in the 2011 New York State report as an imperfect proxy for characterizing access to high level pediatric cardiology care in New York State (New York State Department of Health Cardiac Services Program, 2011). We could not assess where individuals in our surveillance system received care for surgeries and other invasive cardiac procedures outside of the surveillance region; therefore, our definition of surgical care may have excluded some facilities where cardiac surgical procedures were performed during the surveillance period. Conversely, it may have been warranted to exclude certain centers due to low cardiac procedure volumes over the surveillance period.

Despite these issues, we believe that our main finding of limited access to comprehensive care in rural areas is sound. However, we expect that any discrepancy between our definition of surgical care centers and centers where surgical care was performed would have a smaller impact on inference for southeastern New York than it would for western New York because of the high number of surgical care centers in the region.

Our surveillance system was comprised of data sources that documented healthcare encounters for individuals with CHDs. It is possible that individuals who would have met our case inclusion criteria were not captured by this system because they did not seek care during the surveillance period or had a healthcare encounter outside of the capture area. If proximity played an important role in care-seeking, individuals near care centers may be disproportionately represented in the surveillance system. Conversely, individuals with nonsevere defects may have been underrepresented, as they may experience multi-year gaps in follow-up cardiac care more often those with severe defects (Gurvitz et al., 2013). It is also important to consider that the surveillance system is comprised of individuals living in 11 New York counties. Although this system has a population-based framework, it is possible that findings would not be generalizable to other areas with different demographic compositions.

We did not have visit appointment times; therefore, we chose to restrict travel time queries to regular working hours. This restriction may be problematic if a large proportion of individuals received CHD care outside of these hours. It should be noted that the Google Maps Distance Matrix API calculates travel times given knowledge of historical and live traffic patterns. Changes in roads and traffic patterns and roads in the years between the surveillance period and the queries for this analysis may have biased our travel time estimates.

The Andersen behavioral model of healthcare use posits that predisposing characteristics, enabling factors, and need contribute to healthcare usage (Andersen, 1995). Our analysis characterized two enabling factors, geographic proximity to surgical care and public transit availability, and captured the impact of several predisposing characteristics, including defect severity, sex, and age, on one-way drive time to surgical care. We were not able to characterize other individual-level enabling factors such as health insurance coverage and income nor other predisposing characteristics such as education, race, and ethnicity in this project. Although we could approximate some of these variables using information at the census-tract level, further work is needed to incorporate additional individual-level factors contributing to healthcare access and usage in this population.

Finally, we treated proximity to nearest center, a potential measure of access, as our outcome rather than a revealed measure of access such proximity to the center where an individual was hospitalized (Guagliardo, 2004). Because individuals may not receive care at the center nearest to them, it is possible that our estimates of geographic proximity to care were underestimated (Casas et al., 2017). Future research on this topic would benefit from incorporating healthcare usage data.

Despite our limitations, our work has several important strengths. First, we used a novel approach to estimate one-way drive time, one-way public transit time, and public transit availability using methods that can be replicated in future work. Second, we used individual-level residential address data which was successfully geocoded at the street level for ≥95% of cases. Third, we estimated access to care using driving distances and times rather than straight line distances to better approximate real-world conditions. Fourth, public transit estimates were incorporated in assessing proximity to care to provide a fuller picture of geographic access. The population targeted for this analysis is somewhat novel as well. Although several studies have evaluated geographic barriers to care among individuals with birth defects, very few have focused specifically on adolescents. Adolescents with CHDs are a population at risk of discontinuation of care, so it is important to characterize factors that may influence their access to healthcare (Heery et al., 2015).

FUTURE DIRECTIONS AND PUBLIC HEALTH IMPLICATIONS

We have shown that applying GIS to birth defects surveillance data can highlight important accessibility patterns. In the future, it would be useful to determine how these barriers influence perceived and realized access to care among adolescents with CHDs. Future work would also benefit from exploring the impact of proximity to care on healthcare outcomes, to expand this analysis to other age groups and regions to see if patterns hold, and to characterize factors beyond geographic access that contribute to receipt of care in this population, such as CHD type/severity, race, ethnicity, the presence of comorbidities, referral patterns, hospital type, and insurance coverage.

Our findings suggest that a considerable number of adolescents with CHDs in our surveillance area have geographic barriers to accessing surgical care, particularly those living in rural areas. This demonstrates the challenge of applying the American College of Cardiology/American Heart Association recommendations that moderate or complex CHD care be coordinated at specialty care centers (Warnes et al., 2008). As previous work has indicated that increased rurality is associated with decreased visits to specialists, relevant stakeholders might consider different platforms to facilitate access in these areas (Chan et al., 2006). Telemedicine has shown to be useful for diagnosing and triaging patients without ready access to a high-level pediatric cardiology center, but few rural hospitals currently have operational cardiology-related telehealth programs (Ward et al., 2014; Satou et al., 2017).

Additionally, a recent survey suggested that many patients in rural areas may be averse to receiving treatment by means of telemedicine (Call et al., 2015). For these reasons, widespread implementation of telemedicine may be difficult. As an alternative, regional CHD care centers might consider providing a telephone line to aid primary care physicians in fielding general patient inquiries (Fernandes and Sanders, 2015). Given the expected shortage of CHD specialists, shifting some management of CHDs to primary care providers through channels such as these may be warranted (Gurvitz et al., 2005). Another option is to explore care delivery through specialist outreach programs to rural areas. Specialist outreach programs have been found to be effective in improving healthcare access and outcomes in rural populations, and underserved areas in New York could be identified by characterizing the availability of such programs relative to the location of individuals with CHDs in New York (Gruen et al., 2004). A report conducted through the Transit Cooperative Research Program found that providing nonemergency medical transportation for transportation-disadvantaged populations was cost effective for all 12 medical conditions considered, including heart disease (Hughes-Cromwick et al., 2005). It would be useful to determine the feasibility and cost implications of providing nonemer-gency medical transportation for the treatment of CHDs. When travel to surgical centers is unavoidable, the impact of travel provision or reimbursement programs on appropriate receipt of care might be considered, particularly for communities in high poverty areas for whom geographic distance to care poses a considerable financial burden.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention. Human subjection protection: This work was approved by the Institutional Review Board of the New York State Department of Health.

Centers for Disease Control and Prevention; contract grant number: CDC-CK12-1202.

Supported by the Centers for Disease Control and Prevention (Grant number: CDC-CK12-1202 – Emerging Infections Program).

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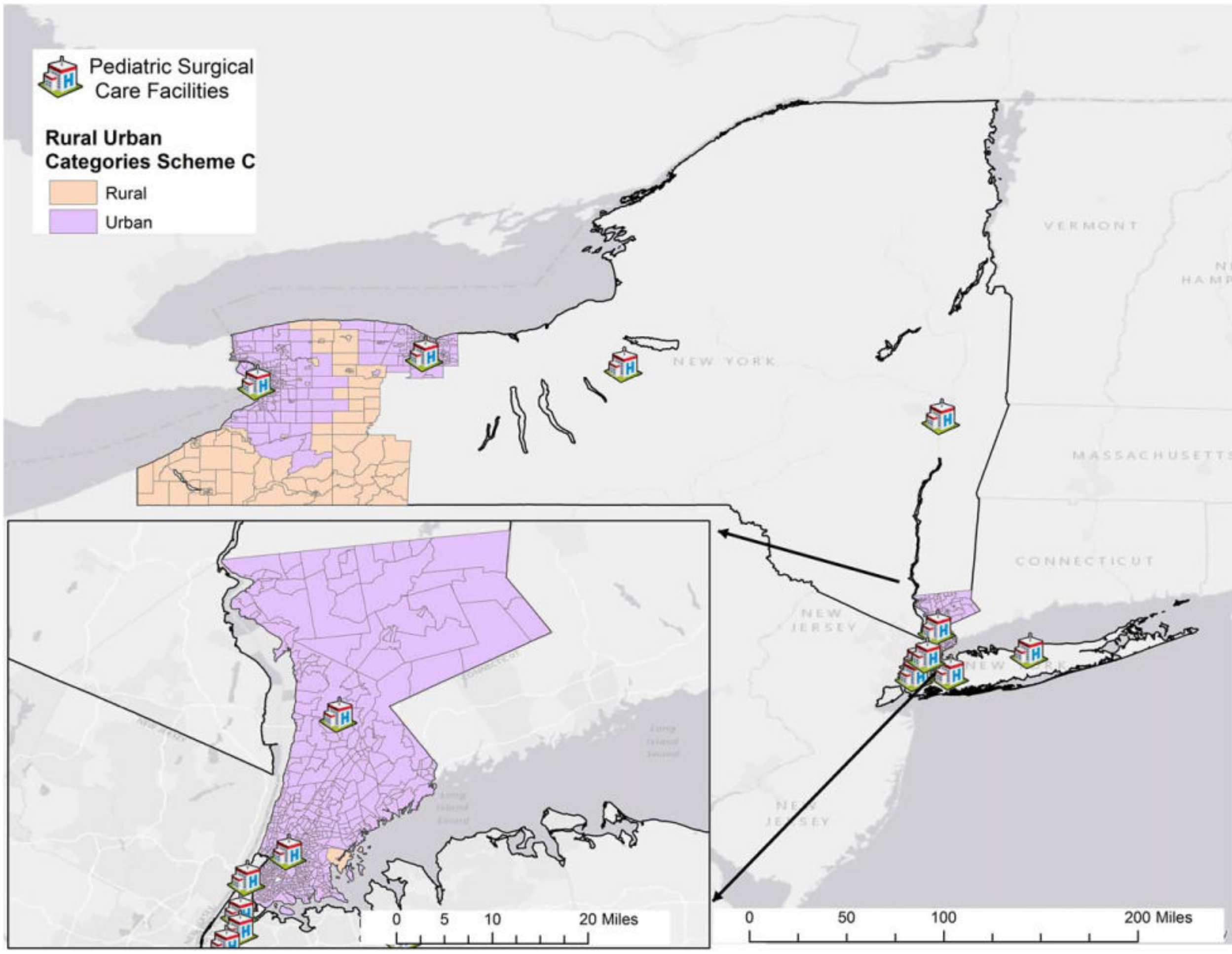

FIGURE 1.

Rural/urban categorization of census tracts in surveillance area counties, New York, 2008 to 2010.

TABLE 1

Characteristics of Adolescents with CHDs in Western and Southern New York, 2008 to 2010

	n **(%)**
Total cases	2522
Age (on January 1, 2010)	
11-13 years	639 (25.3)
14-16 years	970 (38.5)
17-19 years	913 (36.2)
Sex	
Male	1234 (48.9)
Female	1036 (41.1)
Missing[a]	252 (10.0)
CHD severity	
Severe[b]	516 (20.5)
Non-severe[c]	2006 (79.5)

[a]Multiple imputation was used to impute missing values of sex for modeling.

[b]Severe: Defect that requires surgical or catheter intervention in the first year of life.

[c]Non-severe: Defect that does not require surgical or catheter intervention in the first year of life.

TABLE 2

Characteristics of Addresses Reported by Adolescents with CHDs in Western andS New York, 2008 TO 2010

	***n* (%)**
Total addresses	3058
Region-rurality	
Southeastern[a]	1198 (39.2)
Urban western	1576 (51.5)
Rural western	284 (9.3)
Census tract poverty level	
Low poverty area[b]	2032 (66.4)
High poverty area[c]	1026 (33.6)
Census tract minority composition	
Low minority[d]	1966 (64.3)
High minority[e]	1092 (35.7)

[a]Addresses in urban and rural southeastern New York were collapsed.

[b]Low poverty area: <20% of the population was living at or under the federal poverty line.

[c]High poverty area: ≥20% of the population was living at or under the federal poverty line.

[d]Low minority area: ≤50% of the population was non-Hispanic white.

[e]High minority area: >50% of the population was non-Hispanic white.

TABLE 3

Observed One-Way Drive Time and One-Way Public Transit Time to Nearest Pediatric Cardiac Surgical Care Center from Residential Addresses stratified by Region-Rurality and County, New York, 2008 TO 2010

	Total addresses		Addresses where public transit data are available		
	Total *N*	**Drive time median (IQR), minutes**	***N* (% of Total N)**	**Drive time median (IQR), minutes**	**Public transit time median (IQR), minutes**
Overall	3058	18.3 (14.1–26.6)	2301 (75.2)	16.3 (13.3–21.0)	53.1 (33.3–76.3)
Region					
Rural western	284	63.2 (51.8–89.1)	6 (2.1)	51.2 (47.0–52.0)	324.9 (111.7–331.0)
Urban western	1576	21.0 (15.8–27.8)	1244 (78.9)	18.9 (14.8–25.1)	65.5 (46.4–88.1)
Southeastern	1198	15.1 (12.6–18.1)	1051 (87.7)	14.8 (12.5–17.5)	39.6 (26.4–59.8)
County					
Allegany	33	89.4 (78.7–94.8)	0 (0)	–	–
Bronx	671	14.0 (12.2–16.7)	670 (99.9)	14.0 (12.2–16.7)	31.0 (22.1–40.8)
Cattaraugus	66	79.4 (63.5–91.1)	0 (0)	–	–
Chautauqua	96	81.4 (58.6–92.9)	1 (1.0)	47.0 (–)	111.7
Erie	729	22.3 (16.1–27.9)	623 (85.5)	20.7 (15.2–25.5)	60.0 (41.0–84.2)
Genesee	52	39.9 (35.6–43.3)	0 (0)	–	–
Monroe	647	17.5 (14.8–21.9)	524 (81.0)	16.4 (14.1–20.7)	65.5 (49.2–84.3)
Niagara	155	33.8 (29.8–40.4)	98 (63.2)	31.1 (28.4–38.4)	95.3 (79.9–108.2)
Orleans	41	45.5 (41.4–49.0)	0 (0)	–	–
Westchester	527	16.7 (13.4–19.7)	381 (72.3)	16.4 (13.6–18.6)	59.8 (47.7–78.4)
Wyoming	41	54.5 (49.1–56.7)	4 (9.8)	51.9 (51.2–52.0)	328.9 (324.9–323.0)

TABLE 4

Adjusted Coefficients and 95% Confidence Intervals for the Association between Selected Factors and One-Way Drive Time to Nearest Pediatric Cardiac Surgical Care Center, GEE Model (n 5 3058), New York, 2008 to 2010

	β (95% confidence interval)
Intercept	16.38 (15.51–17.25)
Age[a]	0.13 (−0.02, 0.27)
Sex	
Female	Ref
Male	−0.54 (−1.34, 0.26)
Congenital heart defect severity	
Non-severe	Ref
Severe	−0.58 (−1.48, 0.31)
Region-Rurality	
Southeastern	Ref
Urban western	7.94 (7.22, 8.66) *
Rural western	50.46 (47.22, 53.70) *
Census tract poverty	
Low poverty area (<20% poverty)	Ref
High poverty area (≥20% poverty)	−2.06 (−2.61, −3.23) *
Region-Rurality * Poverty	
Southeastern, low poverty area	Ref
Urban western, high poverty area	−5.54 (−6.76, −4.32) *
Rural western, high poverty area	3.92 (−0.66, 8.50)

Estimates are adjusted for all other variables in the model

* Significant in the multivariate model

[a] Additional minutes of drive time for every 1 year increase in age

TABLE 5

Predicted One-Way Drive Times from Residence to Nearest Pediatric Cardiac Surgical Care Center, Stratified by Region-Rurality and Census Tract Poverty, GEE Model,[a] New York, 2008 to 2010

Residential address characteristics	Predicted one-way drive time to surgical care (minutes) (95% confidence interval)
Low poverty area	
Southeastern	16.38 (15.51, 17.25)
Urban western	24.32 (23.30, 25.34)
Rural western	66.84 (63.50, 70.19)
High poverty area	
Southeastern	14.32 (13.54, 15.09)
Urban western	16.72 (15.47, 17.97)
Rural western	68.70 (64.70, 72.70)

[a]Predicted values at reference levels of age, sex, and congenital heart defect severity.