Disparities in Outcomes and Resource Use After Hospitalization for Cardiac Surgery by Neighborhood Income

Brett R. Anderson, MD, MBA, MS,[a] Evan S. Fieldston, MD, MBA, MSHP,[b] Jane W. Newburger, MD, MPH,[c,d] Emile A. Bacha, MD,[e] Sherry A. Glied, PhD[f]

abstract

BACKGROUND: Significant disparities exist between patients of different races and with different family incomes; less is understood regarding community-level factors on outcomes.

METHODS: In this study, we used linked data from the Pediatric Health Information System database and the US Census Bureau to examine associations between median annual household income by zip code and mortality, length of stay, inpatient standardized costs, and costs per day, over and above the effects of race and payer, first for children undergoing cardiac surgery (2005–2015) and then for all pediatric discharges (2012–2015). Median community-level income was examined as continuous and categorical (by quartile) predictors. Hierarchical logistic and censored linear regression models were constructed. To these models, patient and surgical characteristics, year, race, payer, state, urban or rural designation, and center fixed effects were added.

RESULTS: We identified 101 013 cardiac surgical (and 857 833 total) hospitalizations from 46 institutions. Children from the lowest-income neighborhoods who were undergoing cardiac surgery had 1.18 times the odds of mortality (95% confidence interval [CI]: 1.03 to 1.35), 7% longer lengths of stay (CI: 1% to 14%), and 7% higher standardized costs (CI: 1% to 14%) than children from the highest-income neighborhoods. Results for all children were similar, both with and without any major chronic conditions. The effects of neighborhood were only partially explained by differences in race, payer, or the centers at which patients received care. There were no differences in costs per day.

CONCLUSIONS: Children from lower-income neighborhoods are at increased risk of mortality and use more resource intensive care than children from higher-income communities, even after accounting for disparities between races, payers, and centers.

[a]*Division of Pediatric Cardiology, Morgan Stanley Children's Hospital of NewYork-Presbyterian, Columbia University Medical Center, New York, New York;* [b]*Department of Pediatrics, The Children's Hospital of Philadelphia and Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania;* [c]*Department of Cardiology, Boston Children's Hospital, Boston, Massachusetts;* [d]*Department of Pediatrics, Harvard Medical School, Harvard University, Boston, Massachusetts;* [e]*Division of Cardiothoracic Surgery, College of Physicians and Surgeons, Columbia University, New York, New York; and* [f]*The Robert F. Wagner Graduate School of Public Service, New York University, New York, New York*

Dr Anderson conceptualized and designed this study, conducted data analyses, and drafted the initial manuscript; Drs Fieldston, Newburger, Bacha, and Glied contributed to the original study design, reviewed and interpreted data, and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of this work.

DOI: https://doi.org/10.1542/peds.2017-2432

WHAT'S KNOWN ON THIS SUBJECT: Significant health disparities exist; mechanisms of these disparities are not well elucidated. Race and insurance type have been shown to influence mortality and resource use; limited data exist regarding the effects of community-level factors in health care resource–intensive pediatric populations.

WHAT THIS STUDY ADDS: Studying >100 000 cardiac surgical (and >850 000 total) discharges, we found that children from lower-income neighborhoods have higher mortality and use more resources than do children from higher-income neighborhoods; these disparities are only partially explained by differences in race, insurance, or center.

To cite: Anderson BR, Fieldston ES, Newburger JW, et al. Disparities in Outcomes and Resource Use After Hospitalization for Cardiac Surgery by Neighborhood Income. *Pediatrics.* 2018;141(3):e20172432

A growing body of literature describes associations between neighborhood characteristics and health, with patients from lower-income communities demonstrating worse outcomes.[1–9] For conditions such as obesity, asthma, and low birth weight, plausible mechanisms are reasonably apparent, and targeted interventions are being tested.[9–11] For other conditions, mechanisms are less well understood.

Children with congenital heart defects (CHDs) represent an important population for the study of health disparities. CHDs are the most common birth defects managed in the United States and are associated with both the highest mortality[12] and the highest inpatient resource use,[13] with children (particularly at the more severe end of the disease spectrum) generally well-integrated into the health care system. In addition, there is a well-established, reasonably robust metric for risk adjustment that makes population-based analyses feasible.[14]

We hypothesized that lower median neighborhood-level income is associated with higher mortality and increased resource use and that these differences persist after controlling for patient- and household-level factors, such as disease severity, race, use of public insurance, and center. We used linked data from the Pediatric Health Information System (PHIS) database and the US Census Bureau to test associations between median annual household income by zip code and risk-adjusted in-hospital mortality, lengths of stay, and standardized inpatient hospital costs for children treated at tertiary pediatric hospitals. We first explored these associations within the specific, high-risk, high-resource–intensive cohort of children undergoing congenital heart surgery and then included all children admitted to a PHIS member institution for any reason, with or without a major chronic condition.

METHODS

Data Source

Patient characteristics and outcomes were obtained from the PHIS database for the years 2005–2015. PHIS is an administrative database that contains inpatient encounter-level hospital data, including demographics, diagnoses, and procedures, from 49 US tertiary pediatric hospitals. Data quality and reliability are assured through joint efforts between hospitals, the Children's Hospital Association (Overland Park, KS), and Truven Health Analytics (Ann Arbor, MI).

Data were linked at the patient-level to estimates of neighborhood household income (by zip code) in 2015 dollars, obtained from the US Census Bureau; only deidentified data were released to investigators. Data from 46 hospitals were included.

Study Participants

In our primary analysis, we included all children <19 years of age, discharged from a PHIS member institution with *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes indicating surgical repair of a CHD (October 1, 2005–October 1, 2015). Surgical repair of a CHD was defined using the Risk Adjustment for Congenital Heart Surgery (RACHS-1) methodology, an established methodology that predicts operative mortality by ICD-9-CM–based diagnostic and/or procedure coding.[15] To focus on structural heart disease, cases coded for cardiac transplantation and neonates undergoing isolated ligation of patent ductus arteriosus are excluded.[15] We also excluded patients for whom zip code or standardized costs were unavailable. It was determined a priori that all centers with >10% missing data for any variable would be excluded; no center met this criterion. This date range represents the last 10 full years that ICD-9-CM coding was used. For our all-child cohort, we included all children discharged from a PHIS member institution from October 1, 2012, to October 1, 2015.

Data Collection

The primary outcomes of interest were (1) mortality, (2) length of stay, and (3) costs. In exploratory analyses, costs per day were also examined. Mortality was defined as all-cause, in-hospital mortality. Length of stay was defined as the length of the total hospital stay. Costs were defined as total, standardized inpatient hospital costs. Standardized costs were used to address high variability in hospital cost accounting. The methods for deriving standardized costs have been previously described.[13] In brief, medians of hospital median costs were calculated for all billed items.[13] Costs were adjusted for inflation (to US 2015 dollars) and for regional differences in costs of living.

The primary predictor of interest was median annual household income by patient zip code (heretofore referred to as neighborhood income). Median neighborhood income was assessed first as a continuous variable and then as a categorical predictor by income quartile. Data were also included on age, sex, race and/or ethnicity, region of the country, urban or rural status, primary payer, prematurity, surgical complexity (RACHS-1 score), and other major noncardiac chronic comorbid conditions.[16] In the all-child cohort, data on major cardiac conditions were also included. Age was defined categorically (≤30 days, 31 days–1 year, 1–4 years, 5–12 years, and ≥13 years). Race and/or ethnicity was defined by self-report as white, black/African American, Hispanic or Latino, Asian, or other. Individuals with unreported or missing race were included as other. Urban or rural status was defined by using rural-urban commuting area codes (https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes). Primary payer was recorded as "public" (Medicaid, Medicaid-managed care, Children's Health Insurance Program, and Title V), "privately purchased, commercial, or employer-based," "uninsured" (self-pay or charity), or "other" (Medicare, TRICARE or other government insurance, worker's compensation, missing payer information, and no charge). Prematurity was defined as a hospital-reported gestational age or ICD-9-CM code for ≤36 completed weeks (765.00–765.28). Major chronic comorbid conditions were defined by using previously reported criteria.[16]

Data Analysis

Patient demographics, baseline characteristics, and operative characteristics were described by using standard summary statistics. Locally weighted scatterplot smoothing was used to determine the best models to describe relationships between neighborhood income and the measured outcomes; relationships were reasonably modeled as linear. For ease of interpretation, median household income was also modeled as a categorical variable by quartile. Univariable analyses were used to describe differences across income quartiles, regions, and procedure risk categories. Logistic and Tobit censored linear[17] regression models were then constructed. To these models, clinical characteristics, year, race, payer, state, urban or rural designation, and hospital were added as fixed effects, and the attenuation of the primary predictor of interest was assessed. To explore the possibility of effect modification, interactions were tested between neighborhood income and race, insurance type, age, RACHS-1 score (for the cardiac models), major chronic condition, and region. Models were tested by including first center[5] and then neighborhood (zip code) random effects. Because some patients were admitted more than once, logistic models were also tested by including patients as second-level random effects. Multilevel modeling is not currently possible for Tobit regression. Therefore, sensitivity analyses for linear models excluded repeat admissions. Linear models were also tested excluding extreme outliers.

Statistical analyses were conducted in Stata software, version 13 (StataCorp, College Station, TX). This study was classified as nonhuman subjects research by the Columbia University Medical Center Institutional Review Board, under 45CFR46.102(f).

RESULTS

For the cardiac cohort, 104 443 individual surgical hospitalizations were identified across 46 institutions in 27 states. Of these, 3428 cases were excluded because the zip code was unavailable. Two were excluded because costs were unavailable. This resulted in 101 013 hospitalizations, representing 86 104 unique patients from 21 207 (of 43 000) US zip codes.

Approximately one-quarter of cases (n = 24 987) involved patients operated on as neonates; 60% (n = 59 887) involved children in their first year of life. Roughly half (53%; n = 53 602) of operations were performed on white non-Hispanic children; 18% (n = 18 557) were performed on Hispanic or Latino children; and 12% (n = 12 300) were performed on black non-Hispanic children. In total, 45% (n = 45 501) of children had public insurance. A slightly higher proportion of cases from the highest-income neighborhoods had an unknown insurance type (1.7% vs 0.8%; $P < .001$). Supplemental Table 6 displays differences in baseline characteristics by surgical complexity.

Neighborhood-Level Household Income

The median patient had a median community-level income of $41 437 (interquartile range [IQR]: $32 808–$53 982; range: $6330–$193 717). Patients from communities in the lowest income quartile were more likely black/African American or Hispanic or Latino (23.8% vs 11.4%; $P < .001$) and on public insurance (65.5% vs 22.0%; $P < .001$). A greater percentage of patients in the lowest neighborhood income quartile were premature (4.9% vs 3.6%; $P < .001$), and a greater percentage had comorbid conditions (39.1% vs 34.4%; $P < .001$). Patients from the highest-income communities had a lower proportion of neonatal operations (22.6% vs 25.3%; $P < .001$) and, concordantly, a lower proportion of the highest-risk procedures (2.8% vs 3.7%; $P < .001$), as defined by RACHS-1 categories 5 and 6 and the Norwood and neonatal Ebstein's procedures (Table 1).

Mortality

Overall, 2.9% of patients undergoing cardiac surgery died (n = 2933): 3.5% of patients from the lowest neighborhood income quartile versus 2.2% from the highest ($P < .001$) (Table 2, Fig 1). Mortality was <1% for the lowest surgical risk category and 14.1% for the highest (Supplemental Table 6). After adjusting for clinical characteristics and operative year, cases performed on patients from the lowest neighborhood income quartile had 1.31 times the odds of mortality as did patients from

TABLE 1 Baseline and Operative Characteristics by Median Neighborhood Annual HHI-Q for Children Undergoing Congenital Heart Surgery

	Entire Cohort (*N* = 101 013)	HHI-Q1: Median Annual Household Income ≤$32 808 (*n* = 25 250)	HHI-Q2: Median Annual Household Income $32 808–41 437 (*n* = 25 250)	HHI-Q3: Median Annual Household Income $41 437–53 982 (*n* = 25 235)	HHI-Q4: Median Annual Household Income >$53 982 (*n* = 25 278)	*P*
Patient age						<.01*
<30 d	24 987 (24.7)	6399 (25.3)	6498 (25.7)	6374 (25.3)	5716 (22.6)	—
30 d–1 y	34 900 (34.6)	8961 (35.5)	8723 (34.6)	8788 (34.8)	8428 (33.3)	—
1–4 y	21 818 (21.6)	5450 (21.6)	5421 (21.5)	5361 (21.2)	5586 (22.1)	—
5–12 y	12 200 (12.1)	2933 (12.3)	2916 (12.3)	2983 (12.8)	3368 (15.4)	—
≥13 y	7108 (7.0)	1507 (6.0)	1692 (6.7)	1729 (6.9)	2180 (8.6)	—
Sex, male	55 870 (55.3)	13 935 (55.2)	14 074 (55.7)	13 879 (55.0)	13 982 (55.3)	.43
Race and/or ethnicity						<.01*
White, non-Hispanic	53 602 (53.1)	10 486 (41.5)	13 517 (53.5)	14 134 (56.0)	15 465 (61.2)	—
Black, non-Hispanic	12 300 (12.2)	4989 (19.8)	3029 (12.0)	2501 (9.9)	1781 (7.1)	—
Hispanic or Latino	18 557 (18.4)	6008 (23.8)	5123 (20.3)	4549 (18.0)	2877 (11.4)	—
Asian	3305 (3.3)	409 (1.6)	533 (2.1)	819 (3.3)	1544 (6.1)	—
Other	13 249 (13.1)	3358 (13.3)	3048 (12.1)	3232 (12.8)	3611 (14.3)	—
Payer						
Public	45 501 (45.0)	16 537 (65.5)	13 284 (52.6)	10 128 (40.1)	5552 (22.0)	<.01*
Private, commercial, or employer-based	40 810 (40.4)	5834 (23.1)	8600 (34.1)	11 095 (44.0)	15 281 (60.5)	—
Uninsured	1857 (1.8)	331 (1.3)	473 (1.9)	526 (2.1)	527 (2.1)	—
Other or missing	12 845 (12.7)	2548 (10.1)	2893 (11.5)	3486 (13.8)	3918 (15.5)	—
Urban	84 200 (83.4)	17 217 (68.2)	19 015 (75.3)	22 927 (90.9)	25 041 (99.1)	<.01*
RACHS-1 score						<.01*
1	11 947 (11.8)	2985 (11.8)	2903 (11.5)	2937 (11.6)	3122 (12.4)	—
2	35 024 (34.7)	8573 (34.0)	8798 (34.8)	8751 (34.7)	8902 (35.2)	—
3	38 014 (37.6)	9513 (37.7)	9450 (37.4)	9514 (37.7)	9537 (37.7)	—
4	12 560 (12.4)	3256 (12.9)	3193 (12.7)	3101 (12.3)	3010 (11.9)	—
5 or 6	3468 (3.4)	923 (3.7)	906 (3.6)	932 (3.7)	707 (2.8)	—
Prematurity	4335 (4.3)	1231 (4.9)	1132 (4.5)	1069 (4.2)	903 (3.6)	<.01*
Other complex chronic condition	37 386 (37.0)	9865 (39.1)	9430 (37.4)	9405 (37.3)	8686 (34.4)	<.01*

Data presented as *n* (%) for categorical variables. HHI-Q, household income quartile; HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4. —, not applicable.
* $P < .05$.

TABLE 2 Mortality, Length of Stay, and Costs by Median Neighborhood Annual HHI-Q for Children Undergoing Congenital Heart Surgery

	Entire Cohort	HHI-Q1: Median Annual Household Income ≤$32 808	HHI-Q2: Median Annual Household Income $32 808–41 437	HHI-Q3: Median Annual Household Income $41 437–53 982	HHI-Q4: Median Annual Household Income >$53 982	*P*
Mortality	2933 (2.9)	875 (3.5)	766 (3.0)	726 (2.9)	566 (2.2)	<.01*
Length of stay, d	8 (4–18)	9 (5–21)	8 (4–19)	8 (4–18)	7 (4–15)	<.01*
% length of stay <72 h	14 523 (14.4)	3195 (12.7)	3500 (13.9)	3720 (14.7)	4108 (16.3)	<.01*
Total standardized costs, US 2015 $, thousands	55 (34–108)	58 (34–118)	57 (34–115)	55 (34–107)	49 (32–93)	<.01*
% total costs <$30 000	19 693 (19.5)	4676 (18.5)	4647 (18.4)	4778 (18.9)	5592 (22.1)	<.01*

Data presented as mean or median (SD or IQR) for continuous variables and *n* (%) for categorical variables. HHI-Q, household income quartile; HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4.
* $P < .05$.

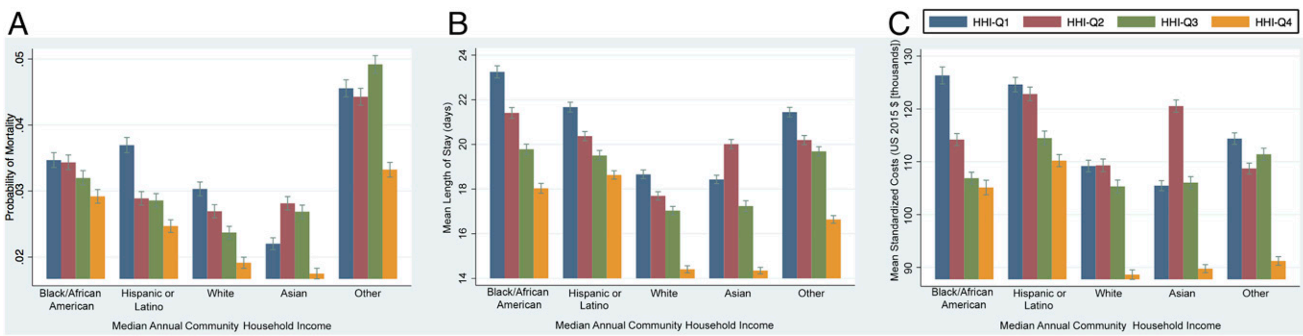

FIGURE 1
Outcome and resource use disparities by race and neighborhood income for children with CHD. Mean predicted probability of A, mortality; B, length of stay; and C, total standardized hospital costs by race and/or ethnicity and neighborhood income quartile, with associated SE. HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4.

the highest income quartile (95 % confidence interval [CI]: 1.14 to 1.51). The magnitude of this association attenuated slightly after adjusting for payer (odds ratio [OR]: 1.22; CI: 1.06 to 1.39). Adjusting for race, state, and urban or rural designation had minimal effect (OR: 1.18; CI: 1.04 to 1.33). When assessed as a linear predictor, for every $10 000 decrease in median household income, the odds of mortality were 1.03 times greater in fully adjusted models (CI: 1.00 to 1.07). There was no evidence of effect modification by race, insurance type, age, region, or case complexity. Adding center fixed effects, or neighborhood or patient random effects, minimally impacted results (Table 3).

In fully adjusted models, patients on public insurance had 1.15 times the odds of mortality as patients not on public insurance (CI: 1.05 to 1.26). Black non-Hispanic children had 1.23 times the odds of mortality as white non-Hispanic children (CI: 1.08 to 1.41) (Supplemental Table 6).

Length of Stay

Median length of stay for all patients undergoing cardiac surgery was 8 days (IQR: 4–18); median length of stay was 2 days longer for patients from the lowest-income neighborhoods when compared with the highest (9 vs 7 days; $P < .001$) (Table 2, Fig 1). After adjusting for clinical characteristics and operative year, operations performed on patients from the lowest neighborhood income quartiles had 9% longer lengths of stay (CI: 3% to 16%) than did operations performed on patients from the highest income quartile. Additional adjustment for race, payer, state, and urban or rural designation had minimal effect on the magnitude of the association between neighborhood income and length of stay (7%; CI: 5% to 8%). When modeling neighborhood income as a linear predictor, for every $10 000 decrease in median household income, length of stay increased by 1% (CI: 0% to 2%). Results were similar after removing outliers for length of stay or reoperations. There was no evidence of effect modification by race, insurance type, age, region, or case complexity. Adding center fixed effects, or neighborhood random effects, minimally impacted results (Table 4).

In fully adjusted models, patients on public insurance had 11% longer

TABLE 3 Associations of Median Neighborhood Annual HHI and Mortality, Under a Range of Modeling Parameters

Cohort	Random Effects	Fixed Effects	Effects of HHI as a Linear Variable (per −$10 000)[a]	P	Effects of HHI-Q on Mortality						
					HHI-Q1	P	HHI-Q2	P	HHI-Q3	P	HHI-Q4
Children undergoing cardiac surgery	Hospital	Unadjusted	1.11 (1.07 to 1.14)	<.01*	1.57 (1.37 to 1.79)	<.01*	1.37 (1.21 to 1.53)	<.01*	1.29 (1.15 to 1.46)	<.01*	Reference
		Adjusted for clinical characteristics[b]	1.06 (1.02 to 1.10)	<.01*	1.31 (1.14 to 1.51)	<.01*	1.19 (1.05 to 1.35)	<.01*	1.14 (1.02 to 1.28)	.03*	Reference
		Adjusted for clinical characteristics[b] and year	1.06 (1.02 to 1.10)	<.01*	1.31 (1.14 to 1.51)	<.01*	1.20 (1.06 to 1.36)	<.01*	1.14 (1.02 to 1.28)	.02*	Reference
		Adjusted for clinical characteristics[b], year, and race	1.05 (1.01 to 1.10)	<.01*	1.28 (1.11 to 1.48)	<.01*	1.20 (1.06 to 1.36)	<.01*	1.14 (1.02 to 1.29)	.03*	Reference
		Adjusted for clinical characteristics[b], year, and payer	1.04 (1.00 to 1.08)	.03*	1.22 (1.06 to 1.39)	<.01*	1.14 (1.01 to 1.28)	.04*	1.11 (1.00 to 1.24)	.06	Reference
		Adjusted for clinical characteristics[b], year, race, and payer	1.04 (1.00 to 1.07)	.03*	1.21 (1.06 to 1.38)	<.01*	1.15 (1.02 to 1.30)	.02*	1.12 (1.00 to 1.25)	.05	Reference
		Adjusted for clinical characteristics[b], year, race, payer, state, and urban designation	1.04 (1.00 to 1.07)	0.04*	1.18 (1.04 to 1.33)	<.01*	1.12 (1.00 to 1.25)	.04*	1.10 (1.00 to 1.21)	.06	Reference
	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1.03 (1.00 to 1.06)	.03*	1.15 (1.01 to 1.32)	.03*	1.12 (1.00 to 1.27)	.06	1.10 (0.98 to 1.24)	.11	Reference
	Hospital and patient	Adjusted for clinical characteristics[b], year, race, payer, state, and urban designation	1.03 (1.00 to 1.06)	.03*	1.15 (1.01 to 1.31)	.03*	1.12 (0.99 to 1.27)	0.06	1.10 (0.98 to 1.24)	.11	Reference
All children	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1.05 (1.03 to 1.07)	<.01*	1.22 (1.13 to 1.31)	<.01*	1.16 (1.08 to 1.25)	<.01*	1.12 (1.05 to 1.20)	<.01*	Reference

Data presented as OR (95% CI) for categorical variables. HHI, household income; HHI-Q, household income quartile; HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4.

[a] A 1-U change in HHI as a linear predictor represents a $10 000 decrease in median annual HHI.

[b] Clinical characteristics included age category, sex, prematurity, other comorbid chronic condition, and RACHS-1 category for children undergoing cardiac surgery.

* $P < .05$.

TABLE 4 Associations of Median Neighborhood Annual HHI and Length of Stay, Under a Range of Modeling Parameters

Cohort	Random Effects	Fixed Effects	Expected Change in Length of Stay by HHI, as a Linear Variable (per −$10 000)[a]	P	Expected Change in Length of Stay (e^{β} − 1) by HHI-Q						
					HHI-Q1	P	HHI-Q2	P	HHI-Q3	P	HHI-Q4
Children undergoing cardiac surgery	Hospital	Unadjusted	5 (4 to 7)	<.01*	26 (17 to 34)	<.01*	17 (12 to 23)	<.01*	12 (7 to 16)	<.01*	Reference
		Adjusted for clinical characteristics[b]	3 (1 to 4)	<.01*	15 (8 to 23)	<.01*	9 (4 to 14)	<.01*	4 (1 to 7)	.01*	Reference
		Adjusted for clinical characteristics[b] and year	3 (1 to 4)	<.01*	9 (3 to 16)	<.01*	5 (1 to 9)	.01*	2 (−1 to 5)	.16	Reference
		Adjusted for clinical characteristics[b], year, and race	3 (1 to 4)	<.01*	9 (3 to 15)	<.01*	5 (1 to 9)	.01*	2 (−1 to 5)	.13	Reference
		Adjusted for clinical characteristics[b], year, and payer	2 (1 to 3)	<.01*	13 (6 to 21)	<.01*	8 (3 to 14)	<.01*	4 (1 to 7)	.02*	Reference
		Adjusted for clinical characteristics[b], year, race, and payer	2 (0 to 3)	<.01*	7 (1 to 14)	.02*	4 (1 to 8)	.03*	2 (−1 to 4)	.16	Reference
		Adjusted for clinical characteristics[b], year, race, payer, state, and urban designation	1 (0 to 2)	<.01*	7 (5 to 8)	<.01*	4 (3 to 6)	<.01*	3 (2 to 4)	<.01*	Reference
	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1 (1 to 2)	<.01*	7 (5 to 9)	<.01*	4 (3 to 6)	<.01*	3 (1 to 4)	<.01*	Reference
All children	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1 (0 to 1)	<.01*	3 (2 to 4)	<.01*	2 (1 to 3)	<.01*	2 (1 to 3)	<.01*	Reference

Data presented as % (95% CI) for categorical variables. HHI, household income; HHI-Q, household income quartile; HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4.
[a] A 1-U change in HHI as a linear predictor represents a $10 000 decrease in median annual HHI.
[b] Clinical characteristics included age category, sex, prematurity, other comorbid chronic condition, and RACHS-1 category.
* $P < .05$.

predicted lengths of stay than patients not on public insurance (CI: 7% to 15%). Patients of Asian descent had 12% longer predicted lengths of stay than white non-Hispanic patients (CI: 8% to 15%); black non-Hispanic children had 8% longer predicted lengths of stay than white non-Hispanic children (CI: 2% to 13%) (Supplemental Tables 7).

Costs

Median inpatient hospital costs for patients undergoing cardiac surgery was $54 726 (IQR: $33 572–$107 703); median costs were $8500 more for patients from the lowest neighborhood income quartile when compared with the highest ($58 077 vs $49 490; *P* < .001) (Table 2, Fig 1). After adjusting for clinical characteristics and operative year, cases performed on patients from the lowest neighborhood income quartile had 11% higher total costs (CI: 3% to 20%) than cases performed on patients from the highest. This association was attenuated moderately after adjusting for payer (6%; CI: −1% to 14%). Adjusting for race, state, and urban or rural designation had minimal effect on the magnitude of the association between neighborhood income and costs (5%; CI: 1% to 8%). When modeling neighborhood income as a linear predictor, for every $10 000 decrease in median household income, costs increased by 1% (CI: 0% to 2%). Results were similar when cost outliers or reoperations were removed. There was no evidence of effect modification by race, insurance type, age, region, or case complexity. Adding center fixed effects, or neighborhood random effects, minimally impacted results (Table 5).

In fully adjusted models, patients on public insurance had 9% higher predicted total hospital costs than patients not on public insurance (CI: 5% to 13%). Patients of Asian

TABLE 5 Associations of Median Neighborhood Annual HHI and Standardized Costs, Under a Range of Modeling Parameters

Cohort	Random Effects	Fixed Effects	Expected Change in Costs by HHI, as a Linear Variable (per −$10 000)[a]	P	Expected Change in Costs ($e^{\beta} - 1$) by HHI-Q						
					HHI-Q1	P	HHI-Q2	P	HHI-Q3	P	HHI-Q4
Children undergoing cardiac surgery	Hospital	Unadjusted	4 (2 to 6)	<.01*	18 (9 to 29)	<.01*	16 (7 to 26)	<.01*	12 (5 to 19)	<.01*	Reference
		Adjusted for clinical characteristics[b]	2 (1 to 4)	<.01*	12 (3 to 20)	<.01*	10 (3 to 19)	<.01*	7 (1 to 13)	.03*	Reference
		Adjusted for clinical characteristics[b] and year	2 (1 to 4)	<.01*	11 (3 to 20)	<.01*	10 (2 to 18%)	.01*	6 (0 to 13)	.04*	Reference
		Adjusted for clinical characteristics[b], year, and race	2 (0 to 4)	.01*	9 (2 to 18)	.02*	9 (2 to 17)	.02*	6 (0 to 12)	.05*	Reference
		Adjusted for clinical characteristics[b], year, and payer	2 (0 to 3)	.07	6 (−1 to 14)	.09	7 (−1 to 14)	.07	4 (−1 to 10)	.12	Reference
		Adjusted for clinical characteristics[b], year, race, and payer	2 (0 to 3)	.06	6 (−1 to 14)	.09	7 (0 to 14)	.05	4 (−1 to 10)	.11	Reference
		Adjusted for clinical characteristics[b], year, race, payer, state, and urban designation	1 (0 to 2)	<.01*	5 (1 to 8)	<.01*	4 (1 to 7)	<.01*	3 (1 to 5)	<.01*	Reference
	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1 (1 to 2)	<.01*	6 (4 to 8)	<.01*	4 (3 to 6)	<.01*	3 (2 to 5)	<.01*	Reference
All children	Neighborhood	Adjusted for clinical characteristics[b], year, race, payer, urban designation, and hospital	1 (0 to 1)	<.01*	3 (2 to 5)	<.01*	3 (1 to 4)	<.01*	1 (0 to 3)	.07	Reference

Data presented as % (95% CI) for categorical variables. HHI, household income; HHI-Q, household income quartile; HHI-Q1, household income quartile 1; HHI-Q2, household income quartile 2; HHI-Q3, household income quartile 3; HHI-Q4, household income quartile 4.

[a] A 1-U change in HHI as a linear predictor represents a $10 000 decrease in median annual household income.

[b] Clinical characteristics included age category, sex, prematurity, other comorbid chronic condition, and RACHS-1 category.

* $P < .05$.

descent had 10% higher predicted costs than non-Hispanic whites (CI: 3% to 17%) (Supplemental Table 7).

Costs per day were not different by neighborhood income or payer. In fully adjusted models, black/African American race was associated with 6% (CI: 1% to 11%) lower standardized costs per day (Supplemental Table 7).

All-Patient Cohort

For the all-patient cohort, 1 175 367 total hospitalizations were identified (2013–2015), representing 857 833 unique patients. Children in this cohort were generally older than in the cardiac cohort (15.6% neonates and 29.6% <1 year, versus 24.7% and 59.3% in the cardiac cohort; $P < .001$), were more often black/African American or Hispanic (38.3% vs 30.6%; $P < .001$), and were more often on public insurance (52.2% vs 45.0%; $P < .001$). Of discharged patients, 43.4% (n = 509 986) had a major chronic condition (32.0% of individual children). In multivariable models, the effects of neighborhood income on outcomes were similar to that observed in the cardiac cohort. After adjusting for clinical characteristics, year, race, payer, urban or rural designation, hospital fixed effects, and neighborhood random effects, children from the lowest-income neighborhoods had 1.22 (CI: 1.13 to 1.31) times the odds of in-hospital mortality, 3% (CI: 2% to 4%) longer lengths of stay, and 3% (CI: 2% to 5%) higher total standardized costs. Results were similar when including hospital and/or patient random effects and when excluding repeat admissions or length of stay and/or cost outliers. There was no evidence of effect modification by race, insurance, region, age, or major chronic condition.

DISCUSSION

In this national, retrospective study, we found that children from lower-income neighborhoods have higher mortality, longer lengths of stay, and use more inpatient resources than children from higher-income neighborhoods and that these differences are only partially explained by differences in race, insurance, or hospital. In addition, we found that these effects persist across ages, races, insurance types, and geographic regions, and are similar for children undergoing high-risk procedures, low-risk procedures, and for children admitted to PHIS member institutions for any reason, with or without a major chronic condition. Differences in resource use appear to be driven largely by differences in length of stay, rather than by differences in costs per day.

It should be noted that we used costs standardized across hospitals and payers in assessing resource use. Thus, observed differences in resource use cannot be explained by differences in hospital accounting or payer mix.

Kucik et al[1] have previously described associations between neighborhood deprivation and 1-year outcomes for children with CHD. In their study, using birth defect surveillance data from 4 states, they controlled for many patient- and household-level factors. However, insurance provider data were unavailable. Therefore, the authors were unable to determine the extent to which observed differences were related to household versus community effects. Dependence on public insurance serves, at least in part, as a proxy for individual household income. In this context, neighborhood median income more closely reflects the socioeconomic well-being of the larger environment in which children live. The fact that payer, race, and neighborhood-level income, in our study, are all significant predictors of the measured outcomes speaks to the important, independent effects of all 3 factors.

When neighborhood disparities have been described in other disciplines, it has been largely hypothesized that the underlying mechanisms for these disparities are either differences in the hospitals used or in environmentally-mediated differences in behavioral health, such as diet, smoking, exercise, or stress.[3,5,6] In a population of young (mostly infant) children undergoing largely planned cardiac operations, these seem unlikely sufficient explanations. Presumably, some differences in the in-utero environment, rates of prenatal diagnosis, and/or timing in referral to subspecialty centers exist.[1,18–22] We also observed some differences in baseline patient characteristics across neighborhood-level income quartiles that might reflect, at least in part, differences in prenatal diagnosis and/or termination or palliative care. Certainly, postnatally diagnosed children with CHD who present in extremis do worse.[22] To the extent to which these are the source of the observed disparities, targeted interventions ought to be implemented to help obstetricians and primary care providers in lower-income communities identify and refer children early. But are these late referrals so frequent as to explain all of the observed effects? Indeed, these data leave us with additional questions that, as medical providers, should prompt introspection as we strive to effect change.[23] Why do we observe separate, independent effects of neighborhood income, race, and payer? Why do disparities across races persist even after controlling for neighborhood and other household factors? After so much effort has gone, in recent years, into developing programs to monitor children with high-risk cardiac lesions (https://npcqic.org/), why do we observe similar disparities in this cohort as in the general pediatric population? Are there differences in families' choices and/or responses to medical advice, intrinsic differences in patients, or are we providing fundamentally different care?

The PHIS database is an administrative database; all standard limitations associated with the use of retrospective administrative data apply, including the potential for incomplete risk adjustment and an inability to imply causality. A few additional limitations specific to this investigation warrant mentioning. First, the neighborhood-level income used in our analysis was by zip code. Incomes or social supports of some subcommunities within zip codes might vary. Second, median income by zip code does not account for regional differences in costs of living. Third, income eligibility for Medicaid varies by state. In addition, although most pediatric patients become Medicaid-eligible on the basis of family income, children may also become eligible on the basis of Supplemental Security Income disability criteria.[24] Fourth, race and/or ethnicity in the database is defined by self-report. Furthermore, our data can only be used to describe in-hospital effects; we cannot answer important questions on differences in prehospital care, operative referral, or postdischarge outcomes. And finally, although our sample included zip codes with median incomes ~\$200 000 per year, neighborhood-level incomes observed in our study were right-skewed; the median income in both our cardiac and general cohorts was ~\$41 000 (IQR:

$33 000–$54 000), which, in 2015, was the equivalent of ~1.7 times (IQR: 1.4–2.2) the federal poverty level for a family of 4.[25] Given this categorization, 22% of children undergoing cardiac surgery from our highest neighborhood income quartile (27% in the general cohort) were on public insurance. Our sample is biased toward younger, less established, families, as >80% of cardiac cases were performed on children <5 years of age (>50% of all pediatric discharges). This highlights the possibility that environmental factors in lower-income neighborhoods might contribute not only to outcomes, but also to disease incidence.

CONCLUSIONS

Children from lower-income neighborhoods are at increased risk of mortality and use more resource-intensive care than children from higher-income communities, even after accounting for already described differences between races, payers, and hospitals. Further investigation is needed to explore etiologies of these disparities and to test interventions to standardize outcomes for children across the health care system.

ABBREVIATIONS

CHD: congenital heart defect
CI: confidence interval
ICD-9-CM: *International Classification of Diseases, Ninth Revision, Clinical Modification*
IQR: interquartile range
OR: odds ratio
PHIS: Pediatric Health Information System
RACHS-1: Risk Adjustment for Congenital Heart Surgery

Accepted for publication Dec 12, 2017

Address correspondence to Brett R. Anderson, MD, MBA, MS, Division of Pediatric Cardiology, Columbia University Medical Center, Morgan Stanley Children's Hospital of NewYork-Presbyterian, 3959 Broadway, CH-2 North, New York, NY 10032-3784. E-mail: bra2113@cumc.columbia.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: Dr Anderson receives salary support from the National Center for Advancing Translational Sciences/National Institutes of Health (KL2 TR001874) and the National Heart Lung and Blood Institute/Nation Institutes of Health (K23 HL133454). Funded by the National Institutes of Health (NIH).

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

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