Association between race/ethnicity, illness severity, and mortality in children undergoing cardiac surgery

Yuen Lie Tjoeng, MD, MS,[a,b] Kathy Jenkins, MD, MPH,[c] Jason F. Deen, MD,[b,d] and Titus Chan, MD, MS, MPP[a,b]

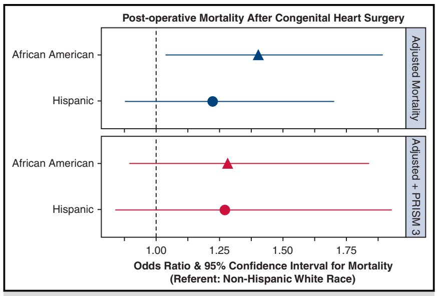
ABSTRACT

Objective: Prior studies demonstrate an association between nonwhite race/ethnicity, insurance status, and mortality after pediatric congenital heart surgery. The influence of severity of illness on that association is unknown. We examined the relationship between race/ethnicity, severity of illness, and mortality in congenital cardiac surgery, and whether severity of illness is a mechanism by which nonwhite patients experience increased surgical mortality.

Methods: We performed a retrospective cohort study of children younger than age 18 years old undergoing cardiac surgery admitted to the intensive care unit (n = 40,545) between 2009 and 2016 from the Virtual Pediatric Systems (VPS, LLC, Los Angeles, Calif) database. Multivariate regression models were constructed to examine the role of severity of illness as a mediator between race/ethnicity and mortality in children undergoing cardiac surgery.

Results: In multivariate models examining severity of illness scores, African-American patients had statistically significant higher severity of illness scores when compared with their white counterparts. In multivariate models of intensive care unit mortality after adjustment for covariates, African-American patients had a higher odds of postoperative mortality (odds ratio, 1.40, 95% confidence interval, 1.04-1.89) when compared with white children. This increased odds of mortality was mediated through higher severity of illness, because adjustment for severity of illness removed this survival disadvantage for black patients.

Conclusions: Although African-American children undergoing cardiac surgery had higher postoperative mortality, this survival difference appears to be mediated via severity of illness. Preoperative and intraoperative factors may be drivers for this survival disparity. (J Thorac Cardiovasc Surg 2020;160:1570-9)



African-American patients have 40% higher odds of death, mediated by illness severity.

CENTRAL MESSAGE

African American race is associated with higher odds of death after congenital heart surgery, mediated by severity of illness. Improving pre- and intraoperative factors may improve this disparity.

PERSPECTIVE

African-American children admitted after congenital heart surgery have 40% higher odds of mortality than white children. However, after adjustment for illness severity, this difference is no longer significant, suggesting that pre- and intraoperative factors may be drivers for this racial disparity. Efforts to improve preoperative access may decrease postsurgical survival disparities.

See Commentaries on pages 1580 and 1582.

Previous studies demonstrate an association between minority race/ethnicity and higher mortality after cardiac surgery in both adult and pediatric populations.[1-4] Referral patterns, management differences after post-operative complications, and differences in use of rescue therapies are contributing etiologies.[3,5] However, the influence of illness severity on racial/ethnic disparities in congenital cardiac surgical outcomes has not been fully examined. Differences in severity of illness may occur

From the Divisions of [a]Critical Care Medicine and [b]Cardiology, Seattle Children's Hospital, and [d]Center of Health Equity, Diversity and Inclusion, School of Medicine, University of Washington, Seattle, Wash; and [c]Department of Cardiology, Boston Children's Hospital, Harvard Medical School, Boston, Mass.
Received for publication Aug 23, 2019; revisions received June 7, 2020; accepted for publication June 12, 2020; available ahead of print June 25, 2020.
Address for reprints: Yuen Lie Tjoeng, MD, MS, Divisions of Critical Care Medicine and Cardiology, Seattle Children's Hospital, 4800 Sand Point Way, NE, M/S: RC.2.820, PO Box 5371, Seattle, WA 98105 (E-mail: Lie.Tjoeng@seattlechildrens.org).
0022-5223/$36.00

https://doi.org/10.1016/j.jtcvs.2020.06.015

Scanning this QR code will take you to the article title page to access supplementary information.

Abbreviations and Acronyms

- CCC = complex chronic conditions
- ICD = International Classification of Diseases
- ICU = intensive care unit
- PICSIM = Pediatric Index of Cardiac Surgical Intensive Care Mortality
- PIM 2 = Pediatric Index of Mortality 2
- PRISM 3 = Pediatric Risk of Mortality 3
- STAT = Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery
- VPS = Virtual Pediatric Systems, LLC

from differential access to primary and subspecialty health services, variations in intraoperative care, and underlying patient complexity. We hypothesized that limited access to subspecialty services leads to greater severity of illness scores at presentation and poorer outcomes for nonwhite children. Delineating the association between race/ethnicity, severity of illness, and cardiac surgical outcomes is vital, enabling health care systems to appropriately allocate resources to reduce identified disparities. If increased severity of illness is a driver of surgical disparities, efforts to address etiologies behind these variations in severity of illness should be the focus of improvement efforts.

We examined the association between race/ethnicity and severity of illness in children undergoing congenital heart surgery in a multi-institutional registry of critically ill children. Furthermore, we evaluated the influence of severity of illness and race/ethnicity on surgical survival.

MATERIALS AND METHODS

We performed a retrospective cohort study using the Virtual Pediatric Systems, LLC (VPS) (Los Angeles, Calif) database, a clinical registry of 154 pediatric intensive care units (ICU) in North America. Hospitals report demographic characteristics, ICU specific data, diagnoses, and procedures. All data were de-identified, qualifying for exemption from human subjects review by the Seattle Children's Hospital Institutional Review Board.

We included patients younger than age 18 years who underwent cardiac surgery during or immediately before admission to the intensive care unit between 2009 and 2016. We included centers that reported race/ethnicity for at least 85% of their entries and limited the population to the United States. All patients with a Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STAT) category were included in the analysis (n = 40,545), which included 72 institutions.

Race/ethnicity was the independent variable of interest in our analysis and categorized into white, African American, Hispanic ethnicity, Asian (included Asian, Indian, and Pacific Islander), American Indian, other, or missing. Other, mixed, and unspecified race/ethnicities were combined into one "other" category.

We analyzed additional variables that may impact surgical survival. Weight in kilograms was coded as a continuous variable. Age at time of ICU admission was categorized into <1 month, 1 month to <12 months, 1 to 9 years, and 10 to 17 years old. Using International Classification of Diseases, Ninth Revision (ICD-9) diagnostic codes, patients born ≤37 weeks' gestation were identified as premature. Due to the high proportion of patients with missing insurance information, insurance status was not included in the analysis.

As a measure of underlying medical complexity, using ICD-9 diagnostic codes, complex chronic conditions (CCC) were assessed[6] and the total number of noncardiac organ systems were grouped as 0, 1, 2, or ≥3 noncardiac organ systems. Diagnostic codes used to categorize noncardiac CCCs are all ICD-9 codes because the transition to ICD-10 did not occur in the VPS database until April 2019.

Surgical complexity was ascertained using the STAT categories, which classify congenital heart surgical procedures from 1 to 5, with 5 being the most complex and associated with the highest risk of mortality.[7] In the VPS dataset, STAT categories are assigned by reviewing the medical record for qualifying cardiac surgical procedures and are coded independently of diagnostic codes.[7] STAT categories were further grouped into low complexity (STAT 1 or 2), moderate complexity (STAT 3 or 4), and high complexity categories (STAT 5). Patients who had multiple surgeries during their admission were categorized into the STAT category of their most complex surgery to capture the highest surgical risk that each patient experienced. Operating room status was categorized as an admission to the ICU directly from the operating room (postoperative admission patients) or from other locations before cardiac surgery (preoperative admission patients). For children admitted directly from the operating room, severity of illness scores reflect both preoperative status, and intraoperative course, whereas severity of illness scores in preoperative admission patients would reflect preoperative status only. We elected to include analysis for both pre- and postoperative admission patients because eliminating patients who were not admitted directly from the operating room would exclude a majority of STAT 5 category operations as well as more than half of the neonates in our patient population.

The dependent outcomes of interest include pediatric critical care measures of severity of illness and ICU mortality, defined as mortality during admission to the ICU after a cardiac surgery. Measures of severity of illness, Pediatric Index of Mortality 2 (PIM 2), Pediatric Risk of Mortality (PRISM 3), and Pediatric Index of Cardiac Surgical Intensive Care Mortality (PICSIM), were analyzed as continuous variables. All 3 scores are computed within the first 4 hours of admission to the ICU and are well validated.[8-10] The PIM 2 score utilizes 10 variables to estimate a probability of death.[8] The more negative a PIM 2 score, the lower the probability of death. PRISM 3 scores are derived from 14 variables, with a higher score indicating a higher risk of mortality.[9] A higher PICSIM score is associated with a higher probability of death and includes 13 variables, including STAT category and a variable for pre- versus postoperative status.[10] Although all 3 severity of illness scores have a right-skewed distribution, linear regression has been effectively used to estimate differences and trends in large, nonnormally distributed datasets.[11]

Previous studies comparing the PICSIM score to PRISM 3 and PIM 2 among cardiac surgical patients demonstrated superiority of PICSIM over these other scores. However, we hypothesized that PICSIM performs better due to the inclusion of surgical complexity adjustment and operating room status data. Additionally, we hypothesized that inclusion of surgical complexity and operating room status into a predictive model that includes PIM 2 or PRISM 3 would be comparable to PICSIM. For this reason, we constructed logistic regression models that predicted mortality using PRISM 3 or PIM 2, STAT category, and operating room status (for PRISM 3) in a training portion of the dataset. We then compared the predicted and observed mortality rates for each STAT category in a testing portion of the dataset.

A univariate analysis was conducted on all potential covariates to assess predictors of illness severity and mortality. The χ^2 test was used for categorical variables. The Mann-Whitney rank sum test and the Kruskal-Wallis test were used for nonnormally distributed continuous and ordinal variables.

Analysis for the association between race/ethnicity, illness severity, and mortality was performed in 2 parts, with white race serving as the reference

CONG

CONG

TABLE 1. Preoperative admission patient characteristics (N = 9440)

Characteristic	White	African American	Hispanic	Asian	American Indian	Other	Missing
n	4507 (48)	1123 (12)	1558 (17)	300 (3)	77 (1)	1195 (13)	680 (7)
Gender							
Female	1910 (42)	511 (46)	674 (43)	126 (42)	30 (39)	537 (45)	296 (44)
Age group							
<1 mo	2423 (54)	492 (44)	701 (45)	129 (43)	48 (62)	717 (60)	532 (78)
1 to <12 mo	1173 (26)	337 (30)	513 (33)	90 (30)	21 (27)	315 (26)	94 (14)
1 to <10 y	486 (11)	159 (14)	210 (13)	57 (19)	7 (9)	96 (8)	31 (5)
10 to <18 y	425 (9)	135 (12)	134 (9)	24 (8)	1 (1)	67 (6)	23 (3)
Weight (kg)	9.9 ± 16.4	12.0 ± 18.8	10.1 ± 16.3	9.6 ± 13.1	5.9 ± 7.6	7.9 ± 14.2	5.8 ± 10.7
Premature (wk)							
≤37	190 (4)	39 (3)	61 (4)	13 (4)	5 (6)	48 (4)	10 (1)
Complex chronic conditions							
None	3452 (77)	847 (75)	1161 (75)	230 (77)	57 (74)	954 (80)	604 (89)
1	732 (16)	181 (16)	267 (17)	47 (16)	15 (19)	169 (14)	57 (8)
2	238 (5)	74 (7)	90 (6)	18 (6)	3 (4)	46 (4)	16 (2)
3 or more	85 (2)	21 (2)	40 (3)	5 (2)	2 (3)	26 (2)	3 (0)
Max STAT category							
1 or 2	1594 (35)	429 (38)	596 (38)	124 (41)	23 (30)	382 (32)	149 (22)
3 or 4	2333 (52)	548 (49)	808 (52)	154 (51)	41 (53)	662 (55)	411 (60)
5	580 (13)	146 (13)	154 (10)	22 (7)	13 (17)	151 (13)	120 (18)
PIM 2 score	−3.6 ± 1.6	−3.7 ± 1.6	−3.7 ± 1.9	−3.9 ± 1.4	−4.0 ± 1.1	−3.6 ± 1.4	−3.2 ± 1.3
PRISM 3 score*	5.8 ± 5.9	6.1 ± 6.2	6.2 ± 5.9	5.8 ± 5.7	5.5 ± 5.4	6.7 ± 6.1	7.8 ± 5.8
PICSIM score × 100*	5.6 ± 8.6	5.6 ± 9.2	4.7 ± 7.0	4.5 ± 6.6	4.3 ± 4.2	6.3 ± 9.0	10.9 ± 12.4

Values are presented as n (%) or mean ± standard deviation. *Max STAT category*, Highest Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery category for admission; *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality. *PRISM 3 score: 658 missing values; PICSIM score: 1341 missing values. No additional missing data unless listed separately above.

group. First, we examined the relationship between race/ethnicity and each severity of illness score using iterative linear regression modeling for preoperative and postoperative admission patients separately. Baseline characteristics were included in our model, including age, weight, gender, and prematurity status. Adjustment for number of CCC groups and STAT category were added to the baseline model. Although some patients were admitted to the ICU preoperatively, STAT category was included in the models to account for anatomical complexity.

We then constructed multivariate logistic regression models to evaluate the association between race/ethnicity and mortality, separating the analysis by preoperative and postoperative admission status, and using the same covariates from the previously constructed severity of illness models. We then added PIM 2 and PRISM 3 scores to examine the role of severity of illness as a mediator between race/ethnicity and mortality. Because the PICSIM score includes the STAT category and operating room status in its calculation, surgical complexity was not included when adjusting for PICSIM score. All regression models adjusted for clustering of outcomes by hospital.

RESULTS

A total of 40,545 patients underwent a STAT category cardiac surgery between January 1, 2009, and December 31, 2016. Of the 154 units reporting to VPS, 111 reported race/ethnicity for >85% of the respective patient population and, of these, 72 units admitted cardiac surgical patients. Of the 43 excluded units that did not report race/ethnicity, 16 units admitted cardiac surgical patients. Among institutions included in the analysis, 53 (75%) of the ICUs were academic affiliated whereas 65% of excluded units performing congenital cardiac surgery were affiliated with an academic center ($P = .48$). To maintain de-identification of ICUs, VPS reports the cardiac surgical volume quartiles for the entire study period and the volume quartile for each institution. There was no difference in cardiac surgical volume quartile distribution between centers that did and did not report race/ethnicity ($P = .13$). The mean STAT category in both included and excluded institutions was also similar (included mean STAT category = 2.51, excluded mean STAT category = 2.19).

Patient characteristics by race/ethnicity and preoperative versus postoperative admission status are described in Tables 1 and 2. More than 75% of patients were admitted to the ICU directly from the operating room (postoperative admission patients). For preoperative admission patients, 48% of patients identified as white, with the next most represented group being Hispanic (17%), other (13%), and African American (12%). There was a similar racial/ethnic composition of the postoperative patients. The majority were male patients and younger than age 1 year in both groups. There was significant variation across

TABLE 2. Postoperative admission patient characteristics (N = 31,105)

Characteristic	White	African American	Hispanic	Asian	American Indian	Other	Missing
n	16,335 (53)	3745 (12)	4906 (16)	1294 (4)	266 (1)	2887 (9)	1672 (5)
Gender							
Female	7265 (44)	1761 (47)	2277 (46)	594 (46)	120 (45)	1317 (46)	769 (46)
Age group							
<1 mo	1975 (12)	353 (9)	548 (11)	91 (7)	23 (9)	417 (14)	59 (4)
1 to <12 mo	6109 (37)	1527 (41)	1852 (38)	462 (36)	123 (46)	1211 (42)	710 (42)
1 to <10 y	5843 (36)	1369 (37)	1956 (40)	550 (43)	91 (34)	1002 (35)	662 (40)
10 to <18 y	2408 (15)	496 (13)	550 (11)	191 (15)	29 (11)	257 (9)	241 (14)
Weight (kg)	16.5 (18.7)	16.2 (18.4)	15.3 (16.8)	15.9 (16.8)	15.3 (17.3)	13.0 (15.3)	16.2 (17.4)
Premature (wk)							
≤37	462 (3)	116 (3)	161 (3)	27 (2)	24 (9)	97 (3)	16 (1)
Complex chronic condition							
None	12,667 (78)	2926 (78)	3801 (78)	1063 (82)	208 (78)	2287 (79)	1488 (89)
1	2675 (16)	587 (16)	813 (17)	166 (13)	49 (18)	432 (15)	156 (9)
2	787 (5)	177 (5)	214 (4)	47 (4)	6 (2)	131 (5)	25 (2)
3 or more	206 (1)	55 (1)	76 (2)	18 (1)	3 (1)	37 (1)	3 (0)
Max STAT category							
1 or 2	10,206 (62)	2337 (62)	3109 (63)	868 (67)	166 (62)	1738 (60)	1070 (64)
3 or 4	5703 (35)	1336 (36)	1691 (34)	413 (32)	97 (36)	1085 (38)	590 (35)
5	426 (3)	72 (2)	106 (2)	13 (1)	3 (1)	64 (2)	12 (1)
PIM 2 score	−4.1 ± 1.2	−4.0 ± 1.3	−4.0 ± 1.2	−4.1 ± 1.1	−4.1 ± 1.2	−3.9 ± 1.2	−4.4 ± 1.2
PRISM 3 score*	7.0 ± 5.0	7.0 ± 5.2	7.0 ± 4.9	6.6 ± 4.6	6.2 ± 5.2	7.1 ± 5.1	6.3 ± 4.5
PICSIM score × 100*	1.8 ± 6.0	1.9 ± 6.3	1.6 ± 5.4	1.3 ± 4.3	1.7 ± 5.1	2.0 ± 6.2	1.3 ± 2.7

Values are presented as n (%) or mean ± standard deviation. *Max STAT category*, Highest Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery category for admission; *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality. *PRISM 3 score: 1466 missing values; PICSIM score: 3012 missing values. No additional missing data unless listed separately above.

all race/ethnicity groups for gender, age, prematurity, number of CCCs, STAT category, and severity of illness scores. Between the 2 groups, preoperative admission patients were more likely to be aged younger than 1 month, have a lower median weight, and a higher proportion of STAT 5 category operations than postoperative patients. Postoperative admission patients had higher PRISM 3 scores, but lower PICSIM risk of mortality scores compared with preoperative admission patients.

There was a statistically significant difference in unadjusted PIM 2, PRISM 3, and PICSIM scores across race/ethnicities (Tables 1 and 2). However, there was no consistent trend for higher severity of illness among any particular racial/ethnic group. Predictors of severity of illness scores are presented in Table 3. Younger age, prematurity, increasing number of CCCs, increasing surgical complexity, and postoperative admission status were associated with greater severity of illness for all or most of the 3 measures (ie, PIM 2, PRISM 3, and PICSIM).

A univariate analysis examining predictors of mortality was also performed (Table 4). African American race, younger age, prematurity, preoperative admission status, increasing severity of illness scores, and increasing surgical complexity were associated with increased mortality. White, American Indian, and Asian patients had the lowest mortality at 2.4%, 1.9%, and 1.8%, respectively. African American and other race/ethnicity had the highest mortality at 3.1% and 3.2%, respectively.

Multivariable linear regression models were analyzed separately by pre- and post-operative admission status (Figure 1 and Table 5). Comparison of predicted and observed mortality rates for each STAT category demonstrated that after adjustment for STAT category, PIM 2 and PRISM 3 predicted mortality as accurately as, if not better than, PICSIM (Figure E1). For this reason, both PIM 2 and PRISM 3 were included as markers of severity of illness. In the preoperative admission group, African American patients had a significantly higher PRISM 3 and PICSIM scores compared with white patients (PRISM 3: β, 0.61; 95% confidence interval [CI], 0.14-1.09; PICSIM β, 0.77; 95% CI, 0.19-1.36). Missing race/ethnicity also had significantly higher PIM 2 and PICSIM scores compared with white race. Other race/ethnicity had higher PRISM 3 scores and American Indian patients had lower PICSIM scores, but only reached significance in 1 of the measures for illness severity. Among postoperative admissions, African-American patients had a significantly higher PIM 2 and PICSIM severity of illness

TABLE 3. Predictors of illness severity

Predictor	PIM 2	PRISM 3*	PICSIM† × 100
Gender			
Male	−4.0 (4.7, 3.2)	6 (3, 10)	0.65 (0.26, 2.21)
Female	−4.1 (4.8, 3.3)	6 (3, 9)	0.62 (0.25, 1.93)
P value	<.01	<.01	<.01
Age group			
<1 mo	−3.5 (4.2, 2.4)	8 (4, 13)	4.85 (2.37, 9.38)
1 to <12 mo	−4.0 (4.5, 3.3)	5 (3, 9)	0.72 (0.35, 1.54)
1 to <10 y	−4.3 (5.4, 3.6)	5 (3, 8)	0.31 (0.17, 0.67)
10 to <18 y	−4.4 (5.5, 3.9)	5 (3, 8)	0.22 (0.12, 0.43)
P value	<.01	<.01	<.01
Weight (kg)‡	−0.20	−0.10	−0.18
P value	<.01	<.01	<.01
OR status			
Postoperative admission	−4.1 (4.9, 3.4)	6 (3, 10)	0.47 (0.22, 1.25)
Preoperative admission	−3.9 (4.6, 2.7)	5 (1, 9)	2.76 (0.83, 7.06)
P value	<.01	<.01	<.01
Premature (wk)			
≤37	−4.0 (4.8, 3.3)	6 (3, 9)	0.62 (0.25, 2.01)
>37	−3.8 (4.4, 3.0)	7 (3, 12)	1.48 (0.51, 4.22)
P value	<.01	<.01	<.01
Complex chronic conditions			
None	−4.1 (4.8, 3.3)	6 (3, 9)	0.58 (0.23, 2.07)
1	−4.0 (4.5, 3.4)	6 (3, 10)	0.77 (0.34, 1.92)
2	−4.0 (4.5, 3.3)	7 (3, 11)	0.89 (0.37, 2.55)
3 or more	−4.0 (4.5, 3.3)	7 (3, 11)	1.07 (0.46, 3.22)
P value	<.01	<.01	<.01
Max STAT category			
1 or 2	−4.3 (5.3, 3.7)	5 (3, 8)	0.31 (0.17, 0.64)
3 or 4	−3.8 (4.3, 3.0)	7 (4, 11)	1.76 (0.75, 4.32)
5	−2.4 (3.4, 1.6)	10 (5, 15)	7.69 (4.16, 13.16)
P value	<.01	<.01	<.01

Values are presented as 50th (25th, 75th) percentiles. *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality, PICSIM, Pediatric Index of Cardiac Surgical Intensive Care Mortality; *OR status*, direct admission from operating room; *Max STAT category*, highest Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery category for admission. *PRISM 3 score: 2124 missing values. †PICSIM score: 4353 missing values. No additional missing data unless listed separately above. ‡Illness severity versus weight in kilograms reported as Pearson correlation coefficient.

score compared with white patients (PIM 2: β, 0.12; 95% CI, 0.00-0.24; PICSIM β, 0.26; 95% CI, 0.00-0.51). Hispanic patients and other category patients had significantly higher PIM 2 scores compared with white patients, but did not reach significance in other severity of illness models.

In the mediation analysis, before adjustment for severity of illness, race/ethnicity was not significantly associated with mortality in the preoperative admission patients. The addition of severity of illness scores did not change this finding. In the postoperative admission patients, before adjustment for severity of illness, African-American patients had a 40% higher odds of mortality compared with white patients (odds ratio [OR], 1.40; 95% CI, 1.04-1.89). However, after adjusting for each of the 3 severity of illness scores, race/ethnicity was no longer associated with increased odds of mortality (PIM 2: OR, 1.30; 95%

TABLE 4. Predictors of mortality

Predictor	Survived	Died	*P* value
Race/ethnicity			<.01
White	20,344 (98)	498 (2)	
African American	4718 (97)	150 (3)	
Hispanic	6299 (97)	165 (3)	
Asian	1564 (98)	30 (2)	
American Indian	337 (98)	6 (2)	
Other	3951 (97)	131 (3)	
Missing	2288 (97)	64 (3)	
Gender			.32
Male	21,793 (97)	560 (3)	
Female	17,703 (97)	484 (3)	
Age group			<.01
<1 mo	7900 (93)	608 (7)	
1 to <12 mo	14,235 (98)	302 (2)	
1 to <10 y	12,433 (99)	86 (1)	
10 to <18 y	4933 (99)	48 (1)	
Weight (kg)	7.2 (4.1-16.0)	3.4 (2.8-5.2)	<.01
OR status			<.01
Postoperative admission	30,608 (98)	497 (2)	
Preoperative admission	8893 (94)	547 (6)	
Premature (wk)			<.01
≤37	1057 (94)	66 (6)	
>37	35,042 (98)	891 (2)	
Complex chronic conditions			<.01
None	31,025 (98)	720 (2)	
1	6133 (97)	213 (3)	
2	1786 (95)	86 (5)	
3 or more	555 (96)	25 (4)	
Max STAT category			<.01
1 or 2	22,618 (99)	173 (1)	
3 or 4	15,243 (96)	629 (4)	
5	1640 (87)	242 (13)	
PIM 2 score	−4.1 (−4.8 to −3.3)	−2.7 (−3.7 to −1.8)	<.01
PRISM 3 score*	6 (3-9)	12 (6-19)	<.01
PICSIM score × 100*	0.61 (0.24-1.92)	7.82 (3.16-22.48)	<.01

Values are presented as n (%) or median (interquartile range). *OR status*, Direct admission from operating room; *Max STAT category*, highest Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery category for admission; *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality. *PRISM 3 score: 2124 missing values; PICSIM score: 4353 missing values. No additional missing data unless listed separately above.

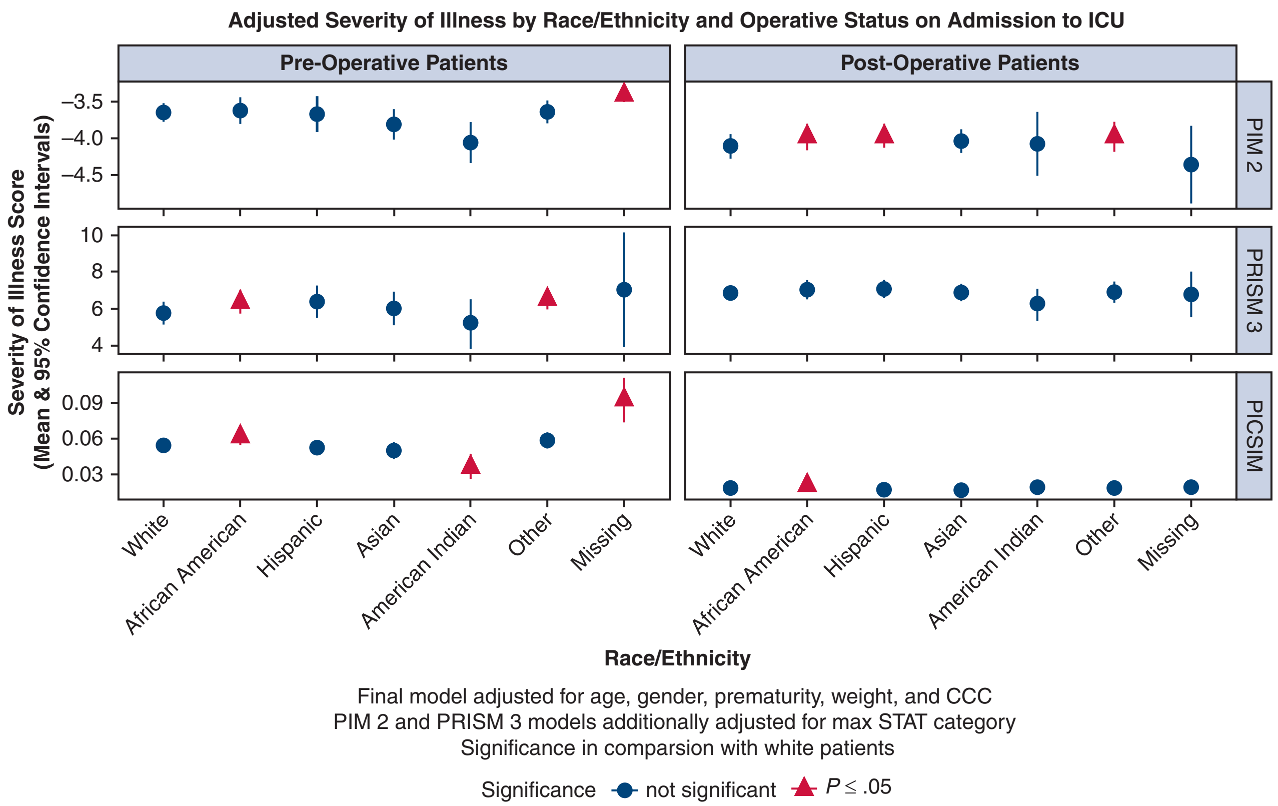


FIGURE 1. Adjusted severity of illness by race/ethnicity and operative status on admission to intensive care unit. This figure demonstrates severity of illness scores by race/ethnicity for 3 different measures of severity of illness: Pediatric Index of Mortality 2 (*PIM 2*), Pediatric Risk of Mortality 3 (*PRISM 3*), and Pediatric Index of Cardiac Surgical Intensive Care Mortality (*PICSIM*) for both preoperative and postoperative admission groups after adjustment for age, gender, prematurity, weight, and number of complex chronic conditions (*CCC*) groups. Models for PIM 2 and PRISM 3 were additionally adjusted for Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (*STAT*) category. STAT category is incorporated into the PICSIM score, so was not included in those models to avoid redundancy. Each severity of illness score for race/ethnicity represents the mean (*dot* or *triangle*) and 95% confidence intervals (minimum and maximum values for vertical line). Statistically significant ($P \leq .05$) differences in severity of illness compared with white patients are represented with a triangle and orange coloring. In the pre- and postoperative admission populations, African-American children had a significantly higher severity of illness scores compared with white children for 2 out of the 3 measures, reflecting higher severity of illness score at admission. *Preoperative patients*, Patients admitted to the intensive care unit before surgical intervention; *postoperative patients*, patients admitted directly from the operating room to the intensive care unit. *ICU*, Intensive care unit.

CI, 0.97-1.76; PRISM 3: OR, 1.28; 95% CI, 0.89-1.84; PICSIM: OR, 1.31; 95% CI, 0.83-2.07) (Figure 2).

We examined several measures of in-hospital care in the preoperative admission group. There was no significant difference between African-American and white patients in time to first operation, preoperative mechanical ventilation, or use of central venous or arterial catheters. However, overall ICU length of stay was longer among African-American patients (13.6 vs 11.7 days; $P < .01$) when compared with their white counterparts.

DISCUSSION

Racial differences in congenital heart disease outcomes have long been noted in medical literature, but the reasons for this inequity have not been fully elucidated.[12,13] In this cohort of children undergoing congenital heart surgery, African-American children generally had greater severity of illness scores on presentation to the ICU. Among the preoperative admission patients, race/ethnicity was not associated with increased odds of mortality. Among the postoperative admission patients, African-American children had a 40% higher odds of mortality than their white counterparts. However, after adjustment for severity of illness in the logistic regression models, the survival disadvantage among African American patients was eliminated, suggesting that postoperative severity of illness is a mediator between race/ethnicity and mortality (Figure 3). These findings suggest that interventions that target the underlying causes of elevated severity of illness may help improve racial/ethnic disparities in congenital heart surgery.

Because severity of illness scores for postoperative admissions were calculated immediately after admission from the operating room, the scores reflect preoperative course as well as intraoperative factors. Although we are

TABLE 5. Multivariate linear regression models for severity of illness on admission to the intensive care unit*

Admission	White	African American β (95% CI)	Hispanic β (95% CI)	Asian β (95% CI)	American Indian β (95% CI)	Other β (95% CI)	Missing β (95% CI)
Preoperative†							
PIM 2	Ref	0.02 (−0.13 to 0.18)	−0.02 (−0.24 to 0.19)	−0.15 (−0.34 to 0.03)	−0.41 (−0.70 to −0.12)	0.00 (−0.13 to 0.13)	0.24 (0.09 to 0.40)
PRISM 3	Ref	0.61 (0.14 to 1.09)	0.65 (−0.10 to 1.39)	0.31 (−0.42 to 1.04)	−0.54 (−1.85 to 0.78)	0.76 (0.29 to 1.24)	1.31 (−1.84 to 4.46)
PICSIM	Ref	0.77 (0.19 to 1.36)	−0.23 (−0.67 to 0.22)	−0.37 (−1.07 to 0.33)	−1.81 (−2.79 to −0.84)	0.39 (−0.11 to 0.89)	3.87 (1.91 to 5.82)
Postoperative‡							
PIM 2	Ref	0.12 (0.00 to 0.24)	0.14 (0.01 to 0.27)	0.06 (−0.03 to 0.15)	0.03 (−0.36 to 0.41)	0.13 (0.00 to 0.26)	−0.26 (−0.81 to 0.29)
PRISM 3	Ref	0.16 (−0.16 to 0.47)	0.15 (−0.21 to 0.51)	−0.02 (−0.39 to 0.36)	−0.59 (−1.49 to 0.30)	0.03 (−0.34 to 0.41)	−0.13 (−1.43 to 1.17)
PICSIM	Ref	0.26 (0.00 to 0.51)	−0.14 (−0.40 to 0.11)	−0.18 (−0.44 to 0.08)	0.07 (−0.53 to 0.66)	−0.02 (−0.31 to 0.27)	0.07 (−0.09 to 0.24)

CI, Confidence interval; *PIM*, Pediatric Index of Mortality; *Ref*, reference category; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality. *Final model adjusted for age, gender, prematurity, weight, and CCC group. PRISM 3 and PIM 2 model additionally adjusted for max STAT category. †PRISM 3 score: 658 missing values; PICSIM score: 1341 missing values. ‡PRISM 3 score: 1466 missing values; PICSIM score: 3012 missing values. No additional missing data unless listed separately above.

unable to separate preoperative from intraoperative factors, severity of illness appears to be a mediator between race/ethnicity and mortality in this patient group. Assuming these measures of severity of illness accurately represent severity of illness on admission, our findings suggest that barriers to access to subspecialty services, timely surgical interventions, or intraoperative factors may be contributing to the mortality difference between African-American and white patients. Efforts and interventions to decrease differences in preoperative clinical status or intraoperative practices may improve disparities in surgical outcomes.

Our study adds insight into the many potential drivers of health outcome disparities after cardiac surgery. Adult cardiac studies demonstrate that social and economic disparities among minority populations create barriers to accessing the health care system, making late presentation more common for minority populations.[14-16] In pediatrics, 1 study found that children from lower-income neighborhoods undergoing cardiac surgery had a higher odds of mortality.[17] Although the association between preoperative care and severity of illness has not been documented in congenital heart disease, we hypothesized that delays in detection of congenital heart disease and unreliable access to subspecialty services would result in greater severity of illness and, subsequently, poorer clinical outcomes for nonwhite children, which may be true in our postoperative admission population. However, in our severity of illness models restricted to preoperative admission patients, African-American patients and patients with missing race/ethnicity had significantly higher severity of illness scores for 2 out of 3 measures before surgical intervention. Despite this finding, there was no significant difference in mortality for this group, suggesting that in-hospital care was able to overcome this disparity. Previous studies have similarly demonstrated no difference in overall pediatric ICU mortality across race/ethnicity, although these studies did not find significant differences in severity of illness across race/ethnicity nor did they separately examine cardiac surgical patients.[18,19]

The mechanisms by which patients admitted to the ICU before surgery do not demonstrate a survival disparity, but those who arrive immediately postoperatively have a higher adjusted mortality, mediated by illness severity, is unclear. Patients admitted preoperatively to the ICU were mostly neonates undergoing higher complexity surgical procedures than the postoperative group. Because children in the preoperative admission group are admitted before undergoing surgery, they likely have a higher severity of illness before surgery than the postoperative admission group, who may be at home or admitted to lower acuity areas of the hospital before surgery. One possible explanation is that preoperative patients in the ICU may have access to diagnostics and therapies that may allow these patients to recover from any organ dysfunction before surgery, thus, mitigating differences in severity of illness. In contrast, patients who are postoperatively admitted may not have equal access to subspecialty services in the outpatient setting, resulting in a greater degree of organ dysfunction before surgery.

In studies of adult cardiac disease, survival disparities have been attributed to referral of minority races to lower surgical volume centers.[19] Previous adult studies have demonstrated racial/ethnic differences in receipt of myocardial infarction care.[20-23] In a pediatric cardiac surgical population, African-American patients were less likely to receive extracorporeal life support after cardiac surgery,[2,24,25] and although African-American patients did not experience higher rates of complications, they were at higher odds of mortality after experiencing a complication.[5] The etiology for these differences in in-hospital care are not clear. Our results did not demonstrate a significant difference in mortality after adjustment for severity of illness. Instead, our study suggests that efforts to understand and ameliorate congenital cardiac surgery disparities should likely focus on preoperative status or intraoperative factors.

We did not find variations in hospital care that would mitigate differences in severity of illness in the preoperative admission group. One possible factor for overcoming preoperative severity of illness is surgical technical performance,

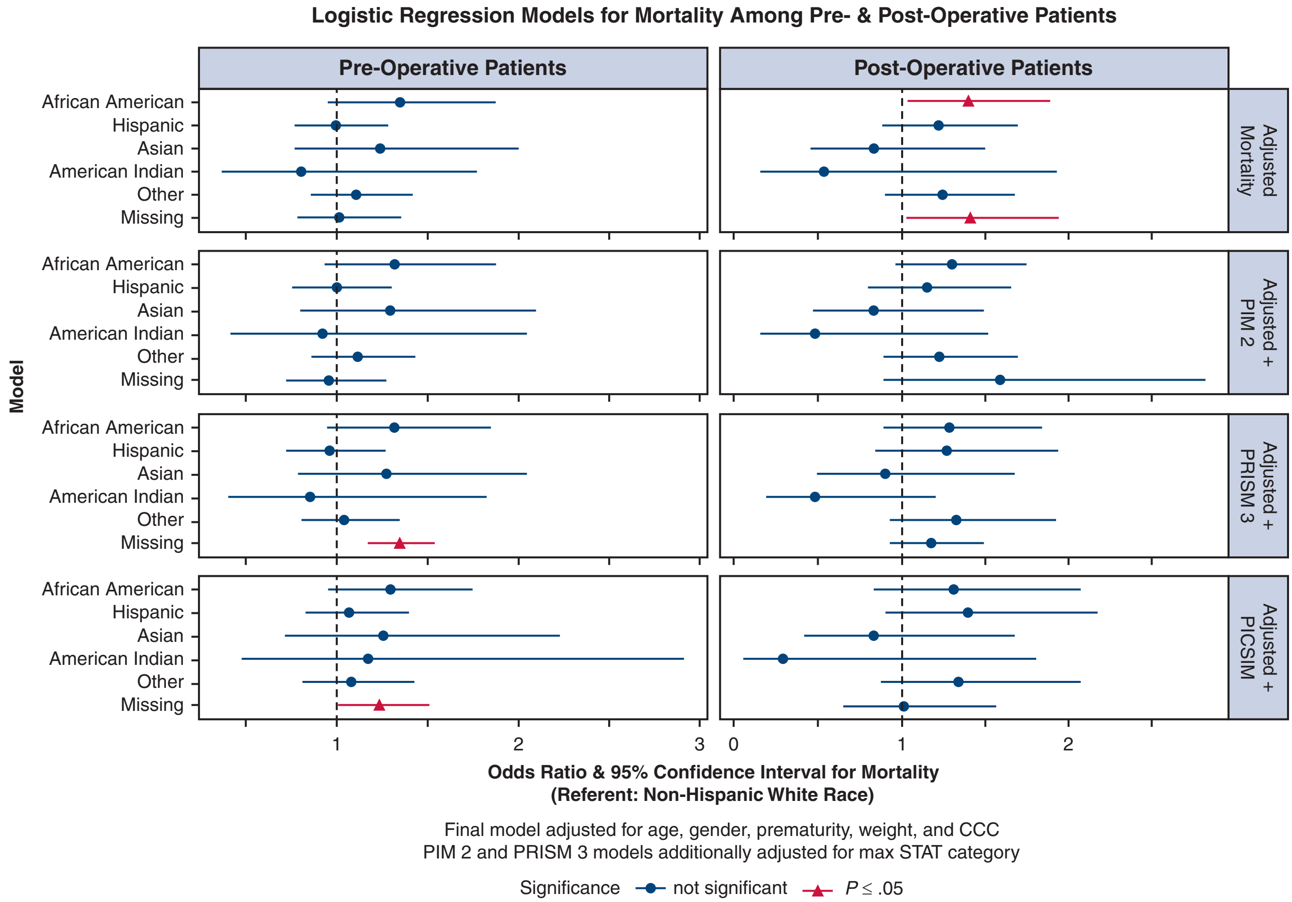


FIGURE 2. Logistic regression models for mortality among pre- and postoperative patients. After adjustment for covariates, African American race was associated with a 40% higher adjusted odds of mortality compared with white patients admitted to the intensive care unit (ICU) immediately postoperatively. Each measure of severity of illness was then added into the model. With adjustment for each measure of illness severity, African American race was no longer associated with mortality, demonstrating that illness severity is a mediator between race/ethnicity and mortality in this patient population. Patients admitted preoperatively did not show any significant difference in mortality across race/ethnicity. *Preoperative patients*, Patients admitted to the intensive care unit before surgical intervention; *Postoperative patients*, patients admitted directly from the operating room to the intensive care unit. *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality; *CCC*, complex chronic condition; *STAT*, Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery.

which reflects the adequacy of the surgical repair or palliation.[26-29] Previous studies demonstrate that an optimal technical repair can attenuate preoperative physiologic derangements.[30] It is possible that technical surgical performance mitigates the effects of illness severity in the higher complexity preoperative group. Nonetheless, longer length of stay among African Americans suggests that severity of illness may still have an influence on clinical course.

Our research has several limitations. Recent articles suggest that PRISM 3 scores are inadequate for accurately predicting mortality in pediatric cardiac populations.[31] However, these prior studies evaluated the performance of the PRISM 3 score without adjusting for surgical complexity. Additionally, we found that models using PIM2 and PRISM3 and STAT category predicted mortality as well as, if not better than, PICSIM. For this reason, we have included all three severity of illness scores in our analysis. Given the observational and retrospective nature of our study, it is subject to limitations involving the collection of data and misclassification. We requested data only from sites reporting at least 85% of race/ethnicity, but 2352 patients (5.8%) of our study population had missing race/ethnicity fields. Although this is a small percentage, we did not want to fully exclude this population; it is important to note that missing race/ethnicity had similar outcomes to African-American patients. Unfortunately, due to the missing data, we cannot make any inferences or conclusions about this group. However, a recent study has explored advanced indirect estimation methods in hopes of addressing this known limitation of incomplete race/ethnicity fields.[32] Other covariates, such as insurance, also had incomplete data, whereas household income, primary language, and parental education were not captured in the dataset, resulting in an

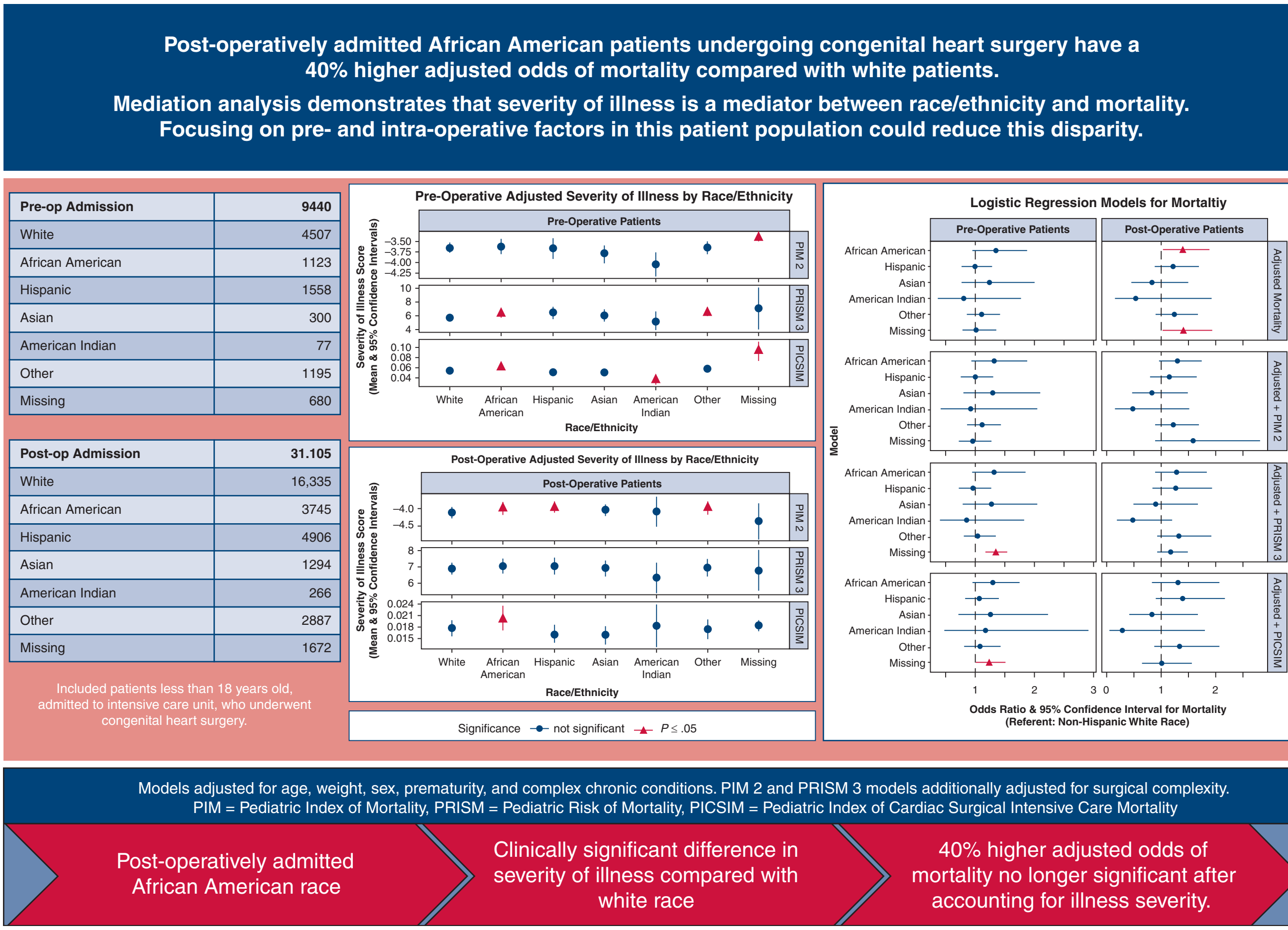


FIGURE 3. African-American patients have 40% higher odds of death, mediated by illness severity.

incomplete assessment for the influence of socioeconomic status on severity of illness or mortality. Additionally, adjusting for PIM 2, PRISM 3, or PICSIM scores may not completely account for the full effect of severity of illness. Some aspects of severity of illness may not be adequately captured in these validated scores. However, it does appear that at least some of the differences in mortality are mediated by severity of illness. We did not include centers reporting race/ethnicity for <85% of their patient population, making generalizations at the national level difficult. However, the included ICUs, although having a similar surgical caseload complexity and volume distribution, comprised the majority of ICUs admitting cardiac surgical patients in the VPS dataset. Our estimates of adjusted mortality from this subpopulation of patients are consistent with previous reports in congenital surgical disparities,[10,33] suggesting a similar patient population to other studies.

CONCLUSIONS

African-American children admitted to an ICU immediately postoperatively after congenital heart surgery have a higher severity of illness on presentation compared with white patients. Furthermore, after adjustment for multiple covariates, African-American patients have 40% higher odds of mortality than their white counterparts. This survival disparity is eliminated after accounting for severity of illness, suggesting that increased severity of illness may be an important driver of health disparities for children undergoing congenital heart surgery. Research focusing on disparities during the preoperative and intraoperative period may help further elucidate the etiologies behind surgical survival disparities (Video 1).

Conflict of Interest Statement

VPS data were provided by Virtual Pediatric Systems, LLC. No endorsement or editorial restriction of the interpretation of these data or opinions of the authors has been implied or stated. The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

VIDEO 1. African-American children admitted to the intensive care unit (ICU) immediately postoperatively after congenital heart surgery have a higher severity of illness on presentation compared with white patients. After adjustment for multiple covariates, African-American patients have a 40% higher odds of mortality than their white counterparts. This survival disparity is eliminated after accounting for severity of illness, suggesting that increased severity of illness may be an important driver of health disparities for children undergoing congenital heart surgery. Preoperative patients were patients admitted to the ICU before surgical intervention, Post-operative patients were those patients admitted directly from the operating room to the ICU. *CCC*, Complex chronic condition; *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality, *STAT*, Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery. Video available at: https://www.jtcvs.org/article/S0022-5223(20)31549-X/fulltext.

References

1. Becker ER, Rahimi A. Disparities in race/ethnicity and gender in in-hospital mortality rates for coronary artery bypass surgery patients. *J Natl Med Assoc*. 2006;98:1729-39.
2. Bradley E, Herrin J, Wang Y, Al E. Racial and ethnic differences in time to acute reperfusion therapy for patients hospitalized with myocardial infarction. *JAMA*. 2004;292:1563-72.
3. Chan T, Pinto NM, Bratton SL. Racial and insurance disparities in hospital mortality for children undergoing congenital heart surgery. *Pediatr Cardiol*. 2012;33:1026-39.
4. DiBardino DJ, Pasquali SK, Hirsch JC, Benjamin DK, Kleeman KC, Salazar JD, et al. Effect of sex and race on outcome in patients undergoing congenital heart surgery: an analysis of the Society of Thoracic Surgeons congenital heart surgery database. *Ann Thorac Surg*. 2012;94:2054-9.
5. Chan T, Barrett CS, Tjoeng YL, Wilkes J, Bratton SL, Thiagarajan RR. Racial variations in extracorporeal membrane oxygenation use following congenital heart surgery. *J Thorac Cardiovasc Surg*. 2018;156:306-15.
6. Feudtner C, Christakis DA, Connell FA. Pediatric deaths attributable to complex chronic conditions: a population-based study of Washington State, 1980-1997. *Pediatrics*. 2000;106:205-9.
7. O'Brien SM, Clarke DR, Jacobs JP, Jacobs ML, Lacour-Gayet FG, Pizarro C, et al. An empirically based tool for analyzing mortality associated with congenital heart surgery. *J Thorac Cardiovasc Surg*. 2009;138:1139-53.
8. Slater A, Shann F, Pearson G. PIM2: a revised version of the paediatric index of mortality. *Intensive Care Med*. 2003;29:278-85.
9. Pollack M, Patel K, Ruttiman U. PRISM III: an updated pediatric risk of mortality score. *Crit Care Med*. 2011;24:743-52.
10. Jeffries HE, Soto-Campos G, Katch A, Gall C, Rice TB, Wetzel R. Pediatric index of cardiac surgical intensive care mortality risk score for pediatric cardiac critical care. *Pediatr Crit Care Med*. 2015;16:846-52.
11. Lumley T, Diehr P, Emerson S, Chen L. The importance of the normality assumption in large public health data sets. *Annu Rev Public Health*. 2002;23:151-69.
12. Nembhard WN, Pathak EB, Schocken DD. Racial/ethnic disparities in mortality related to congenital heart defects among children and adults in the United States. *Ethn Dis*. 2008;18:442-9.
13. Nembhard WN, Xu P, Ethen MK, Fixler DE, Salemi JL, Canfield MA. Racial/ethnic disparities in timing of death during childhood among children with congenital heart defects. *Birth Defects Res A Clin Mol Teratol*. 2013;97:628-40.
14. Bolorunduro O, Smith B, Chumpia M, Valasareddy P, Heckle MR, Khouzam RN, et al. Racial difference in symptom onset to door time in ST elevation myocardial infarction. *J Am Heart Assoc*. 2016;5:1-8.
15. Sheifer SE, Rathore SS, Gersh BJ, Weinfurt KP, Oetgen WJ, Breall JA, et al. Time to presentation with acute myocardial infarction in the elderly: associations with race, sex, and socioeconomic characteristics. *Circulation*. 2000;102:1651-6.
16. Ting HH, Chen AY, Roe MT, Chan PS, Spertus JA, Nallamothu BK, et al. Delay from symptom onset to hospital presentation for patients with non-ST-segment elevation myocardial infarction. *Arch Intern Med*. 2010;170:1834-41.
17. Anderson BR, Fieldston ES, Newburger JW, Bacha EA, Glied SA. Disparities in outcomes and resource use after hospitalization for cardiac surgery by neighborhood income. *Pediatrics*. 2018;141:2017-432.
18. Epstein D, Wong CF, Khemani RG, Moromisato DY, Waters K, Kipke MD, et al. Race/ethnicity is not associated with mortality in the PICU. *Pediatrics*. 2011;127:e588-97.
19. Lopez AM, Tilford JM, Anand KJS, Jo C-H, Green JW, Aitken ME, et al. Variation in pediatric intensive care therapies and outcomes by race, gender, and insurance status. *Pediatr Crit Care Med*. 2006;7:2-6.
20. Birkmeyer JD, Siewers AE, Finlayson EVA, Stukel TA, Lucas FL, Batista I, et al. Hospital volume and surgical mortality in the United States. *N Engl J Med*. 2002;346:1128-37.
21. Bridges CR, Edwards FH, Peterson ED, Coombs LP. The effect of race on coronary bypass operative mortality. *J Am Coll Cardiol*. 2000;36:1870-6.
22. Lucas FL, Stukel TA, Morris AM, Siewers AE, Birkmeyer JD. Race and surgical mortality in the United States. *Ann Surg*. 2006;243:281-6.
23. Trivedi AN, Sequist TD, Ayanian JZ. Impact of hospital volume on racial disparities in cardiovascular procedure mortality. *J Am Coll Cardiol*. 2006;47:417-24.
24. Barnato AE, Lucas FL, Staiger D, Wennberg DE, Chandra A. Hospital-level racial disparities in acute myocardial infarction treatment and outcomes. *Med Care*. 2005;43:308-19.
25. Graham G. Racial and ethnic differences in acute coronary syndrome and myocardial infarction within the United States: from demographics to outcomes. *Clin Cardiol*. 2016;39:299-306.
26. Dehon E, Weiss N, Jones J, Faulconer W, Hinton E, Sterling S. A systematic review of the impact of physician implicit racial bias on clinical decision making. *Acad Emerg Med*. 2017;24:895-904.
27. Green AR, Carney DR, Pallin DJ, Ngo LH, Raymond KL, Iezonni LI, et al. Implicit bias among physicians and its prediction of thrombolysis decisions for black and white patients. *J Gen Intern Med*. 2007;22:1231-8.
28. Hall WJ, Chapman MV, Lee KM, Merino YM, Thomas TW, Payne BK, et al. Implicit racial/ethnic bias among health care professionals and its influence on health care outcomes: a systematic review. *Am J Public Health*. 2015;105:e60-76.
29. Oliver MN, Wells KM, Joy-Gaba JA, Hawkins CB, Nosek BA. Do physicians' implicit views of African Americans affect clinical decision making? *J Am Board Fam Med*. 2014;27:177-88.
30. Karamichalis JM, Nathan M, Henaine R, del Nido PJ, Bacha EA. Assessment of technical competency in pediatric cardiac surgery. *Prog Pediatr Cardiol*. 2012;33:15-20.
31. Parslow RC, Tasker RC, Draper ES, Parry GJ, Jones S, Chater T, et al. Epidemiology of critically ill children in England and Wales: incidence, mortality, deprivation and ethnicity. *Arch Dis Child*. 2009;94:210-5.
32. Fremont A, Weissman J, Hoch E, Elliott M. When race/ethnicity data are lacking: using advanced indirect estimation methods to measure disparities. *Rand Health Q*. 2016;6:16.
33. Russell RA, Rettiganti M, Brundage N, Jeffries HE, Gupta P. Performance of Pediatric Risk of Mortality score among critically ill children with heart disease. *World J Pediatr Congenit Hear Surg*. 2017;8:427-34.

Key Words: congenital heart disease, health disparities, race, ethnicity, mortality, severity of illness, congenital heart surgery

CONG

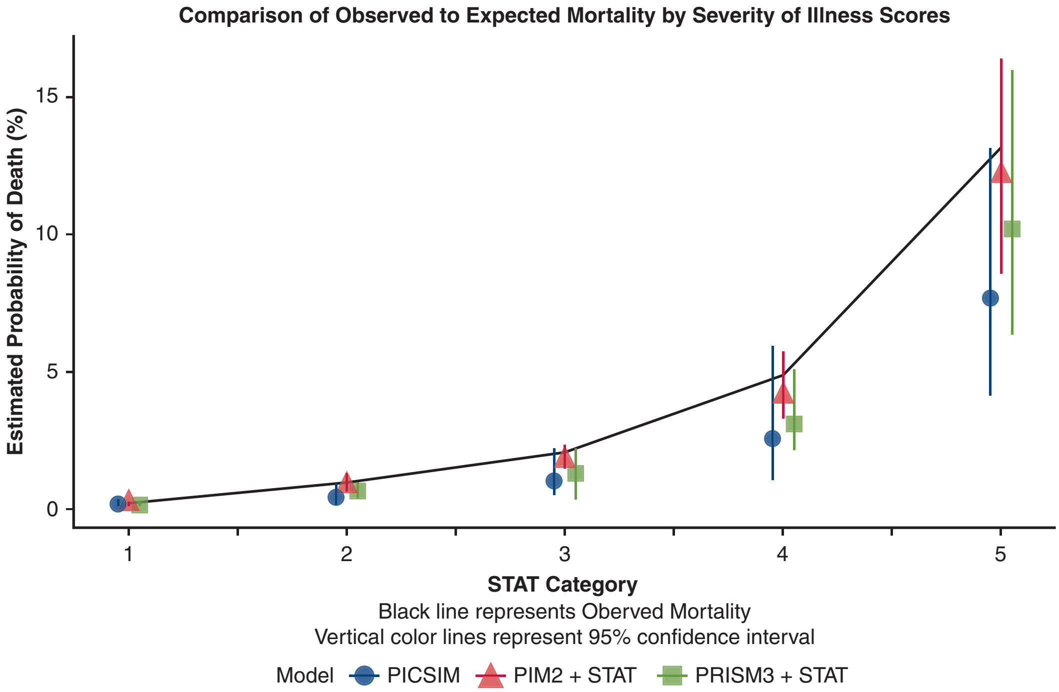


FIGURE E1. Comparison of observed to expected mortality by severity of illness score. *STAT*, Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery; *PICSIM*, Pediatric Index of Cardiac Surgical Intensive Care Mortality; *PIM*, Pediatric Index of Mortality; *PRISM*, Pediatric Risk of Mortality.