ORIGINAL ARTICLE

Social Determinants of Health and Outcomes After Pediatric Ventricular Assist Device Implantation

Caroline L. West[1] | Hong Zhao[2] | Ryan Cantor[2] | Vikram Sood[1] | Ashwin K. Lal[3] | Claude Beaty[4] | James K. Kirklin[2] | David M. Peng[1]

[1]University of Michigan, Ann Arbor, Michigan, USA | [2]Kirklin Solutions, Birmingham, Alabama, USA | [3]University of Utah, Salt Lake City, Utah, USA | [4]Nemours Children's Health, Wilmington, Delaware, USA

Correspondence: Caroline L. West (wecaroli@med.umich.edu)

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ABSTRACT

Background: Limited research exists on the influence of social determinants of health (SDOH) on outcomes in pediatric patients with advanced heart failure receiving mechanical circulatory support.

Methods: Linkage of the Pediatric Interagency Registry for Mechanical Circulatory Support (Pedimacs) and Society of Thoracic Surgeon's Congenital Heart Surgery Database (STS-CHSD) identified pediatric patients who underwent ventricular assist device (VAD) implantation from 2012 to 2022 with available residential zip codes. Utilizing the available zip codes, each patient was assigned a Childhood Opportunity Index (COI) score. Level of childhood opportunity, race, and insurance type were used as proxies for SDOH. Major outcomes included death, transplant, alive with device, and recovery. Secondary outcomes were adverse events. Statistical analyses were performed using the Kaplan–Meier survival, competing risk analyses, and multivariable Cox proportional hazards model.

Results: Three hundred seventeen patients were included in the study. Childhood opportunity level and insurance status did not significantly impact morbidity or mortality after VAD implantation. White race was associated with reduced 1-year survival (71% in White vs. 87% in non-White patients, $p = 0.05$) and increased risk of pump thrombosis ($p = 0.02$).

Conclusion: Childhood opportunity level and insurance status were not linked to morbidity and mortality in pediatric patients after VAD implantation. Notably, White race was associated with higher mortality rates. The study underscores the importance of considering SDOH in evaluating advanced therapies for pediatric heart failure and emphasizes the need for accurate socioeconomic data collection in future studies and national registries.

1 | Introduction

In April 2020, the Scientific Statement by the American Heart Association shed light on the impact of social determinants of health (SDOH) on heart failure outcomes [1]. The authors highlight that individuals facing socioeconomic vulnerabilities encounter challenges in accessing health care and are at a greater risk of enduring unfavorable outcomes related to heart failure in the long term. The authors also offer suggestions for identifying specific SDOH for each individual and putting into action multidisciplinary strategies to effectively tackle these issues.

Although considerable efforts have been dedicated to exploring the influence of SDOH on outcomes among these vulnerable

Abbreviations: COL, childhood opportunity level; STS-CHSD, Society of Thoracic Surgeon's Congenital Heart Surgery Database; Pedimacs, Pediatric Interagency Registry for Mechanical Circulatory Support.

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adults [2], limited knowledge exists regarding SDOH and outcomes in children experiencing advanced heart failure, specifically those receiving mechanical circulatory support. The current study sought to explore whether social determinants of health are associated with morbidity and mortality in pediatric patients after ventricular assist device (VAD) implantation. We hypothesized that pediatric patients with lower socioeconomic status, non-White race, and government insurance experience inferior outcomes after VAD implantation.

2 | Materials and Methods

2.1 | Study Population

Our patient population included pediatric patients (<19 years of age) who underwent implantation of a durable or temporary VAD from September 2012 to July 2022 with available zip codes in either the Pediatric Interagency Registry for Mechanical Circulatory Support (Pedimacs) or Society of Thoracic Surgeon's Congenital Heart Surgery Database (STS-CHSD).

2.2 | Data Sources

Patient information was obtained from the Pedimacs. The Pedimacs was linked to STS-CHSD to obtain patient zip codes.

2.3 | Ethical Approval

Data analyses were performed by the Society of Thoracic Surgeons Access and Publications Research Program. Given the nature of the data, informed consent was not obtained. All work presented is in compliant with the International Society for Heart and Lung Transplantation ethics policies.

2.4 | Social Determinants of Health

The Childhood Opportunity Index 2.0 was utilized as an approximation of overall socioeconomic status. The Childhood Opportunity Index assigns neighborhoods a single composite measure that reflects the quality of the neighborhood. The Childhood Opportunity Index is derived from 29 neighborhood-level indicators. Indicators are represented across three domains: education, health and environment, and social and economic [3]. With the zip code provided by the STS-CHSD, Childhood Opportunity Indices were derived for each patient. Each patient was then assigned to one of five childhood opportunity levels (COL) ranging from very low to very high. Additionally, patient race and insurance type were obtained from the Pedimacs database.

2.5 | Outcomes

Major outcomes included death, transplant, alive with device, and recovery. Adverse events were defined as gastrointestinal bleeding, nongastrointestinal bleeding, infection, device malfunction, and neurologic dysfunction (cerebral vascular accident, ischemic and hemorrhagic stroke). Secondary outcomes for patients with implantable continuous flow devices included discharge alive with the device, death during hospitalization, and transplantation. For patients discharged alive with the device, hospital length of stay (LOS) was assessed.

2.6 | Statistical Analysis

To assess generalizability, the characteristics of the study population were compared with the characteristics of all pediatric patients in the Pedimacs database who underwent implantation of a durable or temporary VAD from September 2012 to July 2022.

Within our study population, key comparison groups of interest were COL (quintiles), race (White, non-White), and insurance status (government, commercial, other). For each comparison group, patient characteristics were presented and evaluated using Student's *t*-test for continuous variables and chi-squared tests for categorical variables. Adverse event rates were compared between groups. Outcome analyses were conducted utilizing the Kaplan–Meier method for survival. The mutually exclusive endpoints of death, transplantation, and recovery were analyzed with competing risk analyses. A multivariable cox proportional hazards model was used to estimate hazards of different risk groups for patient death on a device. Potential covariates were identified by stepwise selection, using a p value of 0.05.

In the secondary analysis, outcomes of patients with dischargeable devices, implantable continuous pumps, were described. The patients were then divided into the aforementioned comparison groups (COL, race, and insurance status), and outcomes were compared using chi-squared tests. Hospital LOS for patients discharged alive with the device were compared using Student's *t*-test.

All analyses were performed with SAS 9.4 software (SAS Institute, Cary, NC), and a p value of <0.05 was considered statistically significant.

3 | Results

There were 1166 pediatric patients who underwent implantation with a VAD from September 2012 to July 2022 included in the Pedimacs database. Zip code information was accessible for 317 patients. When comparing the study cohort to the overall Pedimacs population, there were no significant differences in terms of race, insurance status, patient profile, diagnosis, and kidney function. The average age did not significantly differ between the two cohorts ($p = 0.14$); however, the study group included fewer patients under 1 year of age (20.2% vs. 26.5%, $p = 0.02$) and a higher proportion in the 6- to 10-year age group (22.1% vs. 14.7%, $p = 0.002$). This corresponded with a difference in device class use between the two groups ($p = 0.01$).

Overall demographics and characteristics of the study cohort are displayed in Table 1. The 1-year survival rate after VAD implantation was 78% for our cohort. Rates of competing events at 1 year after VAD implantation were the following: transplantation 67%, death on device 14%, recovery 6%, and alive with device 13% (Figure 1).

TABLE 1 | Demographics and characteristics of overall study cohort.

Patient characteristics	Full cohort ($n = 317$)
Age (y)	8.2 ± 6.1
Weight (kg)	35.1 ± 30.4
Race	
White	175 (55.2)
African American	84 (26.5)
American Indian	1 (0.32)
Asian	5 (1.6)
Mixed race	7 (2.2)
Other	19 (6.0)
Unknown	26 (8.2)
Child opportunity level	
Very high	54 (17.0)
High	44 (13.9)
Moderate	69 (21.8)
Low	76 (24.0)
Very low	74 (23.3)
Insurance	
Private	70 (31.0)
Government	133 (58.8)
Other	23 (10.2)
Diagnosis	
Cardiomyopathy	200 (63.1)
Myocarditis	22 (6.9)
Congenital heart disease	77 (24.3)
Other	18 (5.7)
Single ventricle CHD	41 (53.2)
Biventricular CHD	36 (46.8)
Restrictive cardiomyopathy	10 (5.0)
Dilated cardiomyopathy	185 (92.5)
Hypertrophic cardiomyopathy	4 (2.0)
Patient profile	
1. Critical cardiogenic shock	97 (30.6)
2. Progressive decline	188 (59.3)
3. Stable but inotrope dependent	28 (8.8)
4–7. Resting symptoms or less sick	4 (1.3)
Preimplant device type	
LVAD	273 (86.1)
RVAD	12 (3.8)
BiVAD	31 (9.8)
TAH	1 (0.3)
Device class group	
Implantable continuous	157 (49.5)
Paracorporeal continuous	57 (18.0)
Paracorporeal pulsatile	88 (27.8)
Percutaneous	14 (4.4)
TAH	1 (0.3)
Device strategy	
Bridge to transplant—listed	176 (55.5)
Bridge to candidacy	111 (35.0)
Destination therapy	5 (1.6)
Bridge to recovery	18 (5.7)
Other	7 (2.2)
Previous cardiac operation	135 (42.6)
ALT >100	59 (19.5)
Bilirubin (mg/dL) >1.2	94 (36.2)
eGFR Group	
>60	245 (78.5)
30–60	55 (17.6)
<30	12 (3.8)
Intubated	155 (50.8)
IV therapy at implant	310 (97.8)
Paralyzed	81 (27.3)
Feeding tube or TPN	182 (64.8)
Ambulating	87 (40.3)
Center volume	
Large volume (>20)	216 (68.1)
Medium volume (5–20)	65 (20.5)
Small volume (1–5)	36 (11.4)

Abbreviations: ALT, alanine transaminase; BiVAD, biventricular assist device; eGFR, estimated glomerular filtration rate; LVAD, left ventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart; TPN, total parenteral nutrition.

3.1 | Childhood Opportunity Level

Roughly half of the patients (47%) were assigned to the very low and low COLs (Table 2). Racial distribution was significantly different between the various COLs ($p = 0.002$) with the proportion of white patients increasing with increasing COL. There was an unequal distribution of patients in the 5–9 kg weight group, with a greater percentage of patients of moderate COL ($p = 0.02$). Additionally, of patients described as "stable but

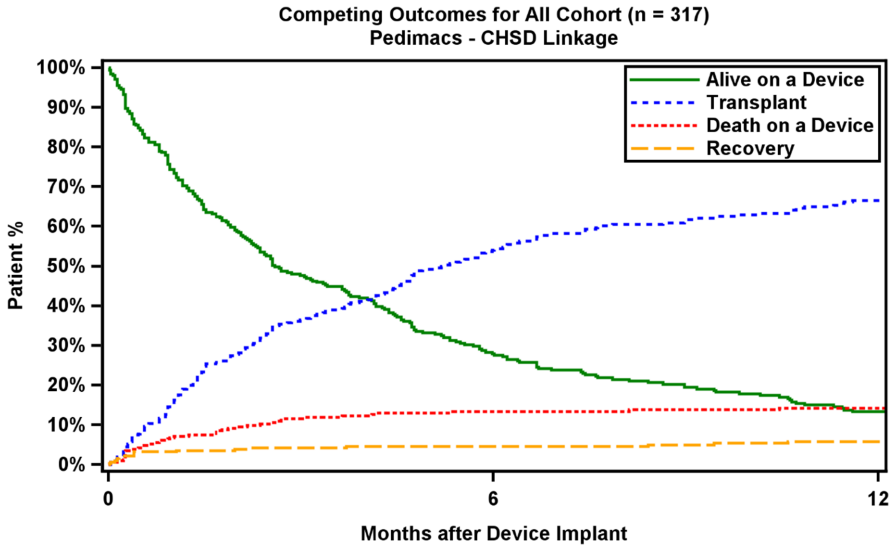


FIGURE 1 | Competing outcomes within the first 12 months after ventricular assist device (VAD) implantation for the overall group of 317 patients receiving implants from September 2012 to July 2022.

inotrope dependent," a greater percentage were in the moderate COL group ($p = 0.03$). There were no differences in rate of adverse events by COL.

There was no association between COL and 1-year survival after VAD implantation ($p = 0.4$) (Figure 2). Childhood opportunity level was not associated with rate of recovery ($p = 0.52$) or transplant ($p = 0.07$) after VAD implantation.

3.2 | Race

The majority of patients were reported as white in the Pedimacs database ($n = 175$, 55%). Other races represented in the non-White racial group ($n = 142$, 45%) included African American ($n = 84$), other ($n = 19$), and unknown ($n = 26$) (see full breakdown in Table 1). There was a significantly different distribution of White and non-White patients into the five COLs, with a greater proportion of white patients in the very high COL and non-White patients in the very low COL ($p < 0.001$). Additionally, non-White patients were more likely to be chemically paralyzed prior to VAD implantation ($p = 0.01$). There were no other significant differences between the white and non-White patients (Table 3). 1-year freedom from thrombus while on device was lower in White patients than in non-White patients (77.9% vs. 93.8%, $p = 0.02$). The rates of all other adverse events were similar.

Race was associated with survival after VAD implantation. 1-year survival for White patients was 71% compared with 87% for non-White patients ($p = 0.05$) (Figure 3). Non-White patients had a higher rate of recovery than white patients (9.2% vs. 3.4%, $p = 0.03$). There was no difference in the rates of transplantation.

3.3 | Insurance Type

The majority of patients had government insurance ($n = 133$, 59%). 31 % ($n = 70$) of patients had private insurance and 10% ($n = 23$) of patients had either self-pay or non-US insurance (other). Insurance type was missing for 91 patients (29%). The distribution of patients with different COLs and races was significantly different among insurance types. Most patients with private insurance were in the high or very high COL whereas most patients with government or "other" insurance were in the very low to low COL. The majority of private and government insurance was obtained by white patients (64% and 56% respectively). Non-White patients had higher rates of government insurance than private or "other" insurance.

Patients with "other" insurance were least likely to have dilated cardiomyopathy compared to patients with government and private insurance ($p = 0.03$). Patients with government insurance were more likely to be characterized as "stable but inotrope dependent" at the time of VAD implant (government 13.5% vs. private 4.3%, $p = 0.03$). There were no other significant differences between patients with different insurance types (Table 4). The risk of hemorrhagic stroke was higher in patients with "other" insurance than those with private or government insurance ($p < 0.001$).

Insurance type was not associated with 1-year survival after VAD implantation. There were no differences in the rates of transplantation or recovery.

3.4 | Multivariable Modeling

The following covariates were included in our multivariable model: female, white race, congenital heart disease, device type, COL, age, body surface area, and weight (kg). Insurance status was not included in the model given the degree of missing data. White race was associated with a reduced survival in the multivariable model (HR 2.01 (1.06–3.80), $p = 0.03$). Congenital heart disease (HR 2.38 (1.29–4.39), $p < 0.01$) and biventricular VAD (HR 6.71 (3.27–13.8), $p < 0.01$) were also associated with reduced survival after implantation.

TABLE 2 | Demographics and clinical characteristics by childhood opportunity level.

Patient characteristics	Very low ($n=74$)	Low ($n=76$)	Moderate ($n=69$)	High ($n=44$)	Very high ($n=54$)	p
Age (y)	7.5 ± 6.1 ($n=74$)	9.1 ± 5.9 ($n=76$)	6.9 ± 6.3 ($n=69$)	8.4 ± 6.4 ($n=44$)	9.3 ± 5.8 ($n=54$)	0.12
Weight (kg)	33.5 ± 30.7 ($n=74$)	39.4 ± 31.1 ($n=76$)	31.2 ± 32.3 ($n=69$)	34.5 ± 28.9 ($n=44$)	36.6 ± 28.1 ($n=54$)	0.57
Race						
White	26 (35.1)	43 (56.6)	40 (58.0)	28 (63.6)	38 (70.4)	0.0024
Non-White	48 (64.8)	33 (43.4)	29 (42)	16 (36.4)	16 (29.7)	
Insurance						
Private	8 (15.4)	9 (15.3)	13 (26.5)	13 (46.4)	27 (71.1)	<0.0001
Government	37 (71.2)	40 (67.8)	32 (65.3)	14 (50.0)	10 (26.3)	
Other	7 (13.5)	10 (16.9)	4 (8.2)	1 (3.6)	1 (2.6)	
Diagnosis						
Cardiomyopathy	45 (60.8)	53 (69.7)	41 (59.4)	28 (63.6)	33 (61.1)	0.35
Myocarditis	8 (10.8)	2 (2.6)	6 (8.7)	3 (6.8)	3 (5.6)	
CHD	17 (23.0)	15 (19.7)	22 (31.9)	9 (20.5)	14 (25.9)	
Other	4 (5.4)	6 (7.9)	—	4 (9.1)	4 (7.4)	
Single ventricle CHD	8 (47.1)	8 (53.3)	12 (54.5)	6 (66.7)	7 (50.0)	0.91
Biventricular CHD	9 (52.9)	7 (46.7)	10 (45.5)	3 (33.3)	7 (50.0)	0.91
Restrictive cardiomyopathy	1 (2.2)	2 (3.8)	2 (4.9)	3 (10.7)	2 (6.1)	0.57
Dilated cardiomyopathy	44 (97.8)	49 (92.5)	38 (92.7)	24 (85.7)	30 (90.9)	0.44
Hypertrophic cardiomyopathy	0 (0.0)	2 (3.8)	1 (2.4)	1 (3.6)	0 (0.0)	0.59
Patient profile						
1. Critical cardiogenic shock	25 (33.8)	18 (23.7)	25 (36.2)	14 (31.8)	15 (27.8)	0.064
2. Progressive decline	48 (64.9)	47 (61.8)	33 (47.8)	27 (61.4)	33 (61.1)	
3. Stable but inotrope dependent	1 (1.4)	9 (11.8)	11 (15.9)	3 (6.8)	4 (7.4)	
4. Resting symptoms or less Sick	—	2 (2.6)	—	—	2 (3.7)	
Preimplant device type						
LVAD	62 (83.8)	70 (92.1)	56 (81.2)	38 (86.4)	47 (87.0)	0.58
RVAD	1 (1.4)	2 (2.6)	5 (7.2)	2 (4.5)	2 (3.7)	
BiVAD	10 (13.5)	4 (5.3)	8 (11.6)	4 (9.1)	5 (9.3)	
TAH	1 (1.4)	—	—	—	—	
Device class group						
Implantable continuous	31 (41.9)	43 (56.6)	24 (34.8)	23 (52.3)	36 (66.7)	0.095
Paracorporeal continuous	12 (16.2)	12 (15.8)	18 (26.1)	7 (15.9)	8 (14.8)	
Paracorporeal pulsatile	26 (35.1)	16 (21.1)	23 (33.3)	13 (29.5)	10 (18.5)	
Percutaneous	4 (5.4)	5 (6.6)	4 (5.8)	1 (2.3)		
TAH	1 (1.4)					

(Continues)

TABLE 2 | (Continued)

Patient characteristics	Very low ($n=74$)	Low ($n=76$)	Moderate ($n=69$)	High ($n=44$)	Very high ($n=54$)	p
Device strategy						
Bridge to Transplant—listed	38 (51.4)	43 (56.6)	44 (63.8)	26 (59.1)	25 (46.3)	0.81
Bridge to candidacy	27 (36.5)	29 (38.2)	19 (27.5)	12 (27.3)	24 (44.4)	
Destination therapy	2 (2.7)	1 (1.3)	—	1 (2.3)	1 (1.9)	
Bridge to recovery	5 (6.8)	3 (3.9)	4 (5.8)	3 (6.8)	3 (5.6)	
Other	2 (2.7)	—	2 (2.9)	2 (4.5)	1 (1.9)	
Previous cardiac operation	34 (45.9)	25 (32.9)	29 (42.0)	23 (52.3)	24 (44.4)	0.28
ALT >100	12 (16.4)	10 (13.9)	13 (20.3)	10 (24.4)	14 (26.9)	0.36
Bilirubin (mg/dL) >1.2	20 (34.5)	25 (39.1)	18 (36.7)	12 (31.6)	19 (37.3)	0.95
eGFR group						
>60	55 (76.4)	62 (82.7)	53 (76.8)	33 (76.7)	42 (79.2)	0.81
30–60	14 (19.4)	11 (14.7)	14 (20.3)	9 (20.9)	7 (13.2)	
<30	3 (4.2)	2 (2.7)	2 (2.9)	1 (2.3)	4 (7.5)	
Intubated	35 (48.6)	32 (43.2)	42 (62.7)	20 (47.6)	26 (52.0)	0.21
IV therapy at implant	74 (100)	73 (96.1)	68 (98.6)	42 (95.5)	53 (98.1)	0.40
Paralyzed	21 (29.6)	19 (25.7)	25 (37.9)	8 (20.5)	8 (17.0)	0.12
Feeding tube or TPN	46 (68.7)	39 (54.9)	42 (73.7)	24 (60.0)	31 (67.4)	0.20
Ambulating	17 (34.7)	29 (50.9)	13 (31.7)	12 (42.9)	16 (39.0)	0.32
Center volume						
Large volume (>20)	53 (71.6)	49 (64.5)	47 (68.1)	30 (68.2)	37 (68.5)	0.72
Medium volume (5–20)	11 (14.9)	19 (25.0)	17 (24.6)	7 (15.9)	11 (20.4)	
Small volume (1–5)	10 (13.5)	8 (10.5)	5 (7.2)	7 (15.9)	6 (11.1)	

Abbreviations: ALT, alanine transaminase; BiVAD, biventricular assist device; eGFR, estimated glomerular filtration rate; LVAD, left ventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart; TPN, total parenteral nutrition.

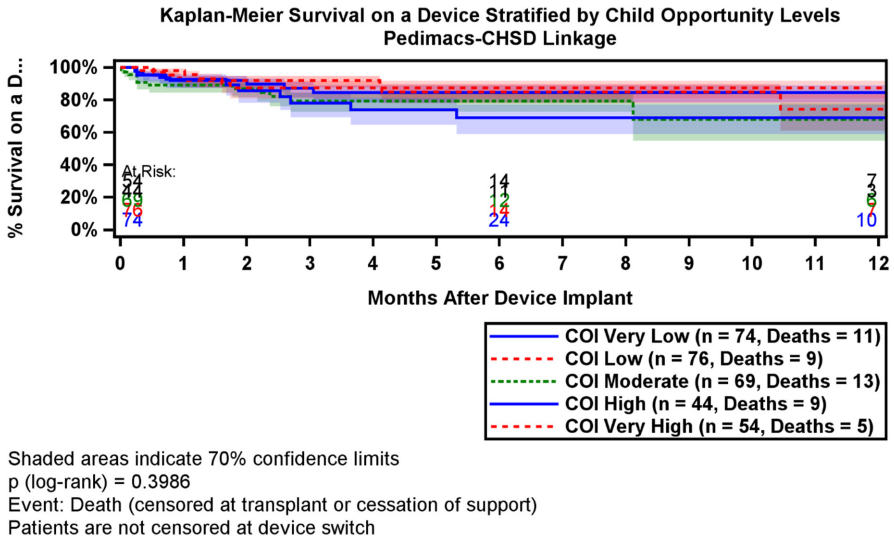


FIGURE 2 | Kaplan–Meier survival curve for the overall group of 317 patients receiving implants between September 2012 and July 2022, stratified by childhood opportunity level.

TABLE 3 | Comparison of demographics and clinical characteristics by White and non-White race.

Patient characteristics	White ($n=175$)	Non-White ($n=142$)	p
Age (y)	8.0 ± 6.2 ($n=175$)	8.4 ± 6.0 ($n=142$)	0.61
Weight (kg)	32.8 ± 28.1 ($n=175$)	37.9 ± 33.0 ($n=142$)	0.14
Child opportunity levels			
Very high	38 (21.7)	16 (11.3)	<0.001
High	28 (16.0)	16 (11.3)	
Moderate	40 (22.8)	29 (20.4)	
Low	43 (24.6)	33 (23.2)	
Very Low	26 (14.9)	48 (33.8)	
Insurance			
Private	45 (35.4)	25 (25.3)	0.046
Government	74 (58.3)	59 (59.6)	
Other	8 (6.3)	15 (15.2)	
Diagnosis			
Cardiomyopathy	104 (59.4)	96 (67.6)	0.19
Myocarditis	13 (7.4)	9 (6.3)	
Congenital heart disease	50 (28.6)	27 (19.0)	
Other	8 (4.6)	10 (7.0)	
Single ventricle CHD	25 (50.0)	16 (59.3)	0.44
Biventricular CHD	25 (50.0)	11 (40.7)	0.44
Restrictive cardiomyopathy	5 (4.8)	5 (5.2)	0.90
Dilated cardiomyopathy	97 (93.3)	88 (91.7)	0.67
Hypertrophic cardiomyopathy	2 (1.9)	2 (2.1)	0.94
Patient profile			
1. Critical cardiogenic shock	48 (27.4)	49 (34.5)	0.43
2. Progressive decline	111 (63.4)	77 (54.2)	
3. Stable but inotrope dependent	14 (8.0)	14 (9.9)	
4–7. Resting symptoms or less sick	2 (1.1)	2 (1.4)	
Preimplant device type			
LVAD	153 (87.4)	120 (84.5)	0.29
RVAD	8 (4.6)	4 (2.8)	
BiVAD	13 (7.4)	18 (12.7)	
TAH	1 (0.6)		
Device class			
Implantable continuous	85 (48.6)	72 (50.7)	0.76
Paracorporeal continuous	29 (16.6)	28 (19.7)	
Paracorporeal pulsatile	52 (29.7)	36 (25.4)	
Percutaneous	8 (4.6)	6 (4.2)	
TAH	1 (0.6)	—	

(Continues)

TABLE 3 | (Continued)

Patient characteristics	White ($n=175$)	Non-White ($n=142$)	p
Device strategy			
Bridge to transplant—listed	97 (55.4)	79 (55.6)	0.24
Bridge to candidacy	66 (37.7)	45 (31.7)	
Destination therapy	1 (0.6)	4 (2.8)	
Bridge to recovery	9 (5.1)	9 (6.3)	
Other	2 (1.1)	5 (3.5)	
Previous cardiac operation	76 (43.4)	59 (41.5)	0.74
ALT >100	36 (21.6)	23 (17.0)	0.32
Bilirubin (mg/dL)>1.2	50 (34.7)	44 (37.9)	0.59
eGFR group			
>60	135 (78.5)	110 (78.6)	0.58
30–60	32 (18.6)	23 (16.4)	
<30	5 (2.9)	7 (5.0)	
Intubated	87 (51.5)	68 (50.0)	0.80
IV therapy at implant	171 (97.7)	139 (97.9)	0.92
Paralyzed	35 (21.5)	46 (34.3)	0.013
Feeding tube or TPN	104 (65.0)	78 (64.5)	0.93
Ambulating	47 (41.2)	40 (39.2)	0.76
Center volume			
Large volume (>20)	120 (68.6)	96 (67.6)	0.32
Medium volume (5–20)	39 (22.3)	26 (18.3)	
Small volume (1–5)	16 (9.1)	20 (14.1)	

Abbreviations: ALT, alanine transaminase; BiVAD, biventricular assist device; eGFR, estimated glomerular filtration rate; LVAD, left ventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart; TPN, total parenteral nutrition.

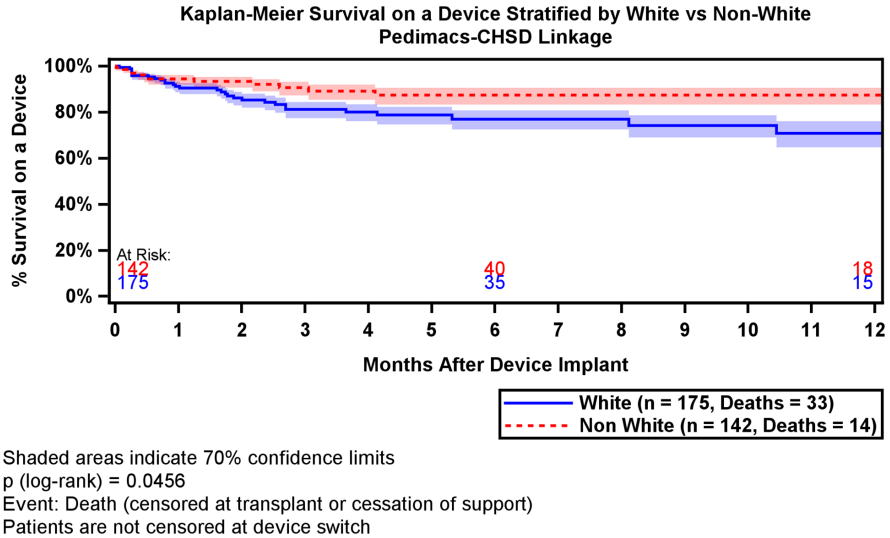


FIGURE 3 | Kaplan–Meier survival curve for the overall group of 317 patients receiving implants between September 2012 and July 2022, stratified by White and non-White race.

3.5 | Outcomes of Patients With Dischargeable Devices

Of those with dischargeable implantable continuous pumps, 62% ($n = 98$) were discharged with the device and 28% ($n = 25$) were transplanted during the implant hospitalization. COL, race, and insurance type were not associated with discharge with device.

For the 98 patients who were discharged with the device, the average length of stay was 1.5 months (SD 1.7 months). The analysis did not show an association between length of stay and COL, race, or insurance type.

4 | Discussion

This is the first multicenter study to evaluate the role of social determinants of health on morbidity and mortality after pediatric VAD implantation. Using surrogates such as childhood opportunity and insurance status, we did not identify overt disparities in the outcomes of patients of different socioeconomic groups once they received a VAD. White race was independently associated with increased mortality after VAD implant in this cohort. Among children receiving implantable continuous VADs, there was no difference in the rate of hospital discharge by childhood opportunity, race, or insurance status.

Previous studies using surrogates for socioeconomic status, such as area-based poverty and annual household income, parental education, and insurance type, describe inferior outcomes of children with socioeconomic risk factors after congenital heart surgery [4]. Davies et al. found that children from regions of lower socioeconomic status have decreased risk-adjusted survival on the heart transplant waiting list and long term after heart transplant. Of note, they also found worse early risk-adjusted posttransplantation mortality among patients with higher socioeconomic scores. This discrepancy was proposed to be related to complexity of the transplantation, as children of high SES were more likely to receive a nationally shared organ with longer ischemic times [5].

Our data showed that outcomes after VAD implant were similar among different COL and insurance types which were used as rough proxies for socioeconomic status. The lack of a glaring disparity after VAD implant may reflect the fact that pediatric patients stay in the hospital for most of their relatively short post-VAD courses. Much less data are available for ambulatory pediatric VAD patients on chronic therapy where social determinants of health may play a larger role. As our experience with chronic VAD therapy in children grows, this will need to be revisited.

We considered whether the Childhood Opportunity Index was an adequate surrogate for SDOH in this unique population. Alternatives, including the Social Vulnerability Index and the Diez Roux score, were considered at the time of study development. The Childhood Opportunity Index was chosen given the ability to distill a multidimensional, contemporary assessment of a child's neighborhood resources and conditions into a single, validated metric [3]. Furthermore, the Childhood Opportunity Index is frequently used in outcome-based research of children with congenital heart disease [6, 7]. By employing a standardized measure of SDOH in this distinctive population, we enhance the comparability of our findings with prior studies.

Black race has long been identified as a predictor of mortality after pediatric heart transplant. Although Black race has been previously associated with 1-year mortality posttransplant [8], evidence points to a more significant effect on late mortality [9–11]. In contrast to our hypothesis, White race was associated with increased 1-year mortality after VAD implant in both univariate and multivariable modeling. Although there were no statistically significant differences in cardiac diagnoses of White and non-White patients in our study, there was a greater percentage of CHD among the white patients. We considered whether the higher mortality observed in white patients after VAD could be attributed to the rate of CHD, as a previous study using the Pedimacs registry showed VAD use in children with CHD is associated with increased mortality compared to those without CHD [12]. However, accounting for congenital heart disease in our multivariable model, White race continued to be a significant predictor of mortality. Furthermore, it is plausible that the impact of race might vary if we extended our outcome assessment to >1 year after the implant, although such an outcome fell outside the scope of our study.

A crucial factor worth investigating is the presence of racial disparities in the selection of pediatric patients for VAD implantation. In a recent retrospective cohort study by Cascino et al. [13] of approximately 12 000 Medicare beneficiaries admitted for heart failure from 2008 to 2014, Black men were 6.0% less likely to receive an LVAD than white men. Among patients with lower propensity for VAD implantation, Black men were less likely to receive a VAD yet had better 1-year survival than White patients with similar propensity scores. The researchers question whether this may be due to less aggressive use of VADs in higher risk patients of color [13]. We hypothesize that this could be one factor for the better outcomes seen in non-White patients in our study. Although white and non-White patients who underwent VAD implantation were grossly similar based on standard clinical descriptors, we were unable to fully account for other potential important risk factors such as frailty, deconditioning, hemodynamics, prior interventions, and other comorbidities in this analysis. Though not answerable by this study, further investigation into the impact of SDOH on candidacy for advanced heart failure therapies in children is warranted.

This is the first study to combine data elements from the Pedimacs and STS-CHSD and demonstrates the feasibility and utility of linking data.

4.1 | Limitations

The study's sample size was limited by the coverage and availability of zip codes within the Pedimacs and STS-CHSD databases. Nevertheless, we were able to obtain zip codes in 317 patients who received VADs during the study period which represents

TABLE 4 | Comparison of demographics and clinical characteristics by insurance type ($n = 226$).

Patient characteristics	Commercial or HMO ($n = 70$)	Government ($n = 133$)	Other ($n = 23$)	p
Age (y)	7.2 ± 6.1 ($n = 70$)	7.9 ± 6.1 ($n = 133$)	9.4 ± 5.8 ($n = 23$)	0.30
Weight (kg)	30.8 ± 29.7 ($n = 70$)	34.9 ± 32.4 ($n = 133$)	41.5 ± 31.7 ($n = 23$)	0.35
Race				
White	45 (64.3)	74 (55.6)	8 (34.8)	0.046
Non-White	25 (35.7)	59 (44.4)	15 (65.2)	
Child opportunity levels				
Very high	27 (38.6)	10 (7.5)	1 (4.3)	<0.0001
High	13 (18.6)	14 (10.5)	1 (4.3)	
Moderate	13 (18.6)	32 (24.1)	4 (17.4)	
Low	9 (12.9)	40 (30.1)	10 (43.5)	
Very Low	8 (11.4)	37 (27.8)	7 (30.4)	
Diagnosis				
Cardiomyopathy	46 (65.7)	83 (62.4)	14 (60.9)	0.80
Myocarditis	3 (4.3)	5 (3.8)	2 (8.7)	
CHD	16 (22.9)	39 (29.3)	5 (21.7)	
Other	5 (7.1)	6 (4.5)	2 (8.7)	
Single ventricle CHD	6 (37.5)	22 (56.4)	4 (80.0)	0.20
Biventricular CHD	10 (62.5)	17 (43.6)	1 (20.0)	0.20
Restrictive cardiomyopathy	1 (2.2)	3 (3.6)	2 (14.3)	0.13
Dilated cardiomyopathy	45 (97.8)	78 (94.0)	11 (78.6)	0.034
Hypertrophic cardiomyopathy	—	2 (2.4)	1 (7.1)	0.25
Patient profile				
1. Critical cardiogenic shock	21 (30.0)	37 (27.8)	10 (43.5)	0.046
2. Progressive decline	44 (62.9)	78 (58.6)	13 (56.5)	
3. Stable but inotrope dependent	3 (4.3)	18 (13.5)	—	
4–7. Resting symptoms or less sick	2 (2.9)	—	—	
Preimplant device type				
LVAD	63 (90.0)	115 (86.5)	20 (87.0)	0.97
RVAD	2 (2.9)	5 (3.8)	1 (4.3)	
BiVAD	5 (7.1)	13 (9.8)	2 (8.7)	
Device class				
Implantable continuous	39 (55.7)	58 (43.6)	9 (39.1)	0.054
Paracorporeal continuous	10 (14.3)	28 (21.1)	4 (17.4)	
Paracorporeal pulsatile	21 (30.0)	37 (27.8)	6 (26.1)	
Percutaneous		10 (7.5)	4 (17.4)	
Device strategy				
Bridge to transplant—listed	35 (50.0)	68 (51.1)	13 (56.5)	0.89
Bridge to candidacy	28 (40.0)	54 (40.6)	7 (30.4)	
Destination therapy	2 (2.9)	1 (0.8)	—	
Bridge to recovery	4 (5.7)	7 (5.3)	2 (8.7)	
Other	1 (1.4)	3 (2.3)	1 (4.3)	

(Continues)

TABLE 4 | (Continued)

Patient characteristics	Commercial or HMO ($n=70$)	Government ($n=133$)	Other ($n=23$)	p
Previous cardiac operation	31 (44.3)	57 (42.9)	10 (43.5)	0.98
ALT >100	17 (25.8)	19 (15.1)	6 (26.1)	0.15
Bilirubin (mg/dL) >1.2	17 (27.9)	37 (36.6)	8 (34.8)	0.51
eGFR group				
30–60	11 (15.9)	22 (16.9)	3 (13.0)	0.98
<30	3 (4.3)	4 (3.1)	1 (4.3)	
>60	55 (79.7)	104 (80.0)	19 (82.6)	
Intubated	36 (51.4)	66 (49.6)	12 (52.2)	0.96
IV therapy at implant	67 (95.7)	132 (99.2)	23 (100)	0.15
Paralyzed	16 (24.2)	37 (27.8)	10 (45.5)	0.16
Feeding tube or TPN	41 (64.1)	81 (65.9)	13 (65.0)	0.97
Ambulating	22 (52.4)	34 (37.4)	8 (42.1)	0.26
Center volume				
Large volume (>20)	47 (67.1)	74 (55.6)	18 (78.3)	0.12
Medium volume (5–20)	14 (20.0)	39 (29.3)	5 (21.7)	
Small volume (1–5)	9 (12.9)	20 (15.0)		

Abbreviations: ALT, alanine transaminase; BiVAD, biventricular assist device; eGFR, estimated glomerular filtration rate; LVAD, left ventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart; TPN, total parenteral nutrition.

the largest such study of this population to date. Furthermore, we compared the study cohort with the overall Pedimacs population and found them largely similar. Additionally, we fully recognize that zip code, COL, and insurance status are imperfect approximations of socioeconomic status. We hope that this study and its limitations further underscore the urgent need to better capture, study, and address SDOH in pediatric heart failure.

5 | Conclusion

Childhood opportunity level and insurance status did not impact outcomes in pediatric patients after VAD implantation including mortality, adverse events, discharge, and transplant rates. White race was associated with increased mortality after VAD implantation. We recommend that future studies evaluate how social determinants of health are considered during evaluation for advanced therapies in pediatrics. Finally, as multiple sectors of the pediatric cardiology community are continuing their work on the creation of national registries, collecting accurate socioeconomic characteristics, and studying their impact on outcomes should be prioritized.

Author Contributions

C.L.W. and D.M.P. contributed to the conception and design. H.Z. and R.C. contributed to the acquisition of the data. All authors participated in the analysis and interpretation of data, drafting, or revising of the manuscript for important intellectual content, and final approval of the version to be published.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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