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ORIGINAL RESEARCH

Mortality and Morbidity of Heart Failure Hospitalization in Adult Patients With Congenital Heart Disease

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BACKGROUND: Little is known about outcomes following heart failure (HF) hospitalization among adults with congenital heart disease (CHD) in the United States. We aim to compare the outcomes of HF versus non-HF hospitalizations in adults with CHD.

METHODS AND RESULTS: Using a national deidentified administrative claims data set, patients with adult congenital heart disease (ACHD) hospitalized with and without HF (ACHDHF+, ACHDHF–) were characterized to determine the predictors of 90-day and 1-year mortality and quantify the risk of mortality, major adverse cardiac and cerebrovascular events, and health resource use. Cox proportional hazard regression was used to compare ACHDHF+ versus ACHDHF– for risk of events and health resource use. Of 26 454 unique ACHD admissions between January 1, 2010 and December 31, 2020, 5826 (22%) were ACHDHF+ and 20 628 (78%) were ACHDHF–. The ACHD HF+ hospitalizations increased from 6.6% to 14.0% (P<0.0001). Over a mean follow-up period of 2.23±2.19 years, patients with ACHDHF+ had a higher risk of mortality (hazard ratio [HR], 1.86 [95% CI, 1.67–2.07], P<0.001), major adverse cardiac and cerebrovascular events (HR, 1.73 [95% CI, 1.63–1.83], P<0.001) and health resource use including rehospitalization (HR, 1.09 [95% CI, 1.05–1.14], P<0.001) and increased postacute care service use (HR, 1.56 [95% CI, 1.32–1.85], P<0.001). Cardiology clinic visits within 30 days of hospital admission were associated with lower 90-day and 1-year all-cause mortality (odds ratio [OR], 0.62 [95% CI, 0.49–0.78], P<0.001; OR, 0.69 [95% CI, 0.58–0.83], P<0.001, respectively).

CONCLUSIONS: HF hospitalization is associated with increased risk of mortality and morbidity with high health resource use in patients with ACHD. Recent cardiology clinic attendance appears to mitigate these risks.

Key Words: adult congenital heart disease ■ heart failure hospitalization ■ mortality

More than 85% of children born with congenital heart disease (CHD) reach adulthood.[1] Late complications are common, and CHD is now considered a chronic condition that requires specialized care across the lifespan.[2] Of the late complications seen in adult congenital heart disease (ACHD), heart failure (HF) is the leading cause of death.[3–6] Using the Nationwide Inpatient Sample, we reported a dramatic increase in ACHD-related HF hospitalizations in the United States in the first 10 years of the new millenium.[7] Yet fundamental questions remain, including which patients are at highest risk of poor outcomes and what are the health resource needs of patients with ACHD following hospitalization for HF. To address these fundamental knowledge gaps, we examined a contemporary cohort of patients with ACHD hospitalized with HF

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CLINICAL PERSPECTIVE

What Is New?

- Heart failure hospitalizations among adults with congenital heart disease is associated with increased risk of 1-year mortality, heart failure rehospitalization, and major adverse cardiac and cerebrovascular events with increased postacute care service use.
- Cardiology clinic visits within 30 days of hospitalization are associated with lower mortality risk for patients with adult congenital heart disease with and without HF.

What Are the Clinical Implications?

- Specialist care pathways are essential for improving outcomes in adults hospitalized with heart failure due to congenital heart disease.

Nonstandard Abbreviations and Acronyms

ACHD	adult congenital heart disease
MACCE	major adverse cardiac and cerebrovascular event

in the United States over the past decade. Using a nationwide longitudinal administrative claims database, patients with ACHD with and without HF hospitalization were characterized to explore the temporal changes in ACHD HF hospitalization, influence of patient characteristics on health outcomes including mortality, major adverse cardiac and cerebrovascular event (MACCE), HF readmission, emergency department (ED) visits, and postacute care use.

METHODS

Study Population

This was a retrospective cohort analysis using deidentified administrative claims data from the OptumLabs Data Warehouse, a database that includes medical and pharmacy claims, and enrollment records, for commercial and Medicare Advantage enrollees representing a diverse mix of ages, races, ethnicities, and geographical regions across the United States.[8] Data are linked longitudinally to provide insights into health care received over time and across the hospital and ambulatory care setting. OptumLabs Data Warehouse has been used extensively to examine population-level health outcomes for people with a range of health conditions including atrial fibrillation[9,10] and HF.[11] Because of the sensitive nature of the data collected for this study, requests to access the data set from qualified researchers trained in human subject confidentiality protocols may be sent to Patricia E. Kern Center for the Science of Healthcare Delivery at yao.xiaoxi@mayo.edu. Informed consent was not obtained as we used a deidentified administrative claims data for analysis. The study was approved by Mayo Clinic institutional review board.

The study population included adult patients aged 18 to 70 years hospitalized between January 1, 2010 and December 31, 2020 with a primary or secondary diagnosis of ACHD. We chose to limit the cohort with an upper age limit of 70 years because patients >70 years are less likely to have clinically important CHD subtypes that are the focus of this study. If the patient had multiple hospitalizations during the study time frame, the first hospitalization was defined as the index hospitalization. To be included in the study, patients were required to have at least 6 months of continuous medical and pharmacy coverage (baseline period) before being hospitalized. Patients with prior heart transplant were excluded. Patients with ACHD were assigned to mutually exclusive groups based on whether they had a diagnosis of HF or not during the index hospitalization, ACHD HF+ and ACHDHF–, respectively. ACHD and HF diagnoses were identified using *International Classification of Diseases, Ninth Revision (ICD-9) Tenth Revision (ICD-10)* (Table S1). ACHD complexity was classified as simple for those with a bicuspid aortic valve, pulmonic stenosis, or an uncomplicated shunt lesion (patent ductus arteriosus, atrial septal defect, or ventricular septal defect without associated pulmonary hypertension). All other ACHD lesions were classified as complex. Comparisons were also undertaken between those with single ventricle circulation versus others. The Mayo Clinic Institutional Review Board exempted this study from review because the study used preexisting, deidentified data.

Covariates

Patient demographics included categories for age (18–24, 25–34, 35–44, 45–54, 55–64, 65–70 years), sex (female or male), race or ethnicity (Asian, Black, Hispanic, White), region (Midwest, Northeast, South, West), health plan type (commercial, Medicare Advantage), and year of index hospitalization. Race and ethnicity were predefined by OptumLabs Data Warehouse. Comorbidities were selected according to clinical relevance and included cardiac arrhythmia, anemia, renal failure, liver disease, diabetes, hypotension, pulmonary hypertension, CHA_2DS_2-VASc score, and cardiology office visit in the 30 days before index hospitalization. The CHA_2DS_2-VASc score was calculated by summing

points determined by risk factors as follows: congestive HF (1 point), hypertension (1 point), age (1 point 65–74 years and 2 points ≥75 years), diabetes (1 point), stroke/transient ischemic attack (2 points), vascular disease (1 point), female sex (1 point).[12] Covariates included indicators for HF diagnosis and ACHD surgery during the index hospitalization and ACHD type (single ventricle, complex).

Outcomes

Patients were followed until end of study period (June 30, 2021), end of enrollment, or death, whichever happened first. Mortality was obtained from the Social Security Administration's Death Master File and discharge status information. Outcomes included predictors of all-cause mortality at 90 days and 1 year. MACCE and health resource use were also assessed including all-cause re-admission, ED visits, and post-acute care. MACCEs were based on the primary diagnosis of the first subsequent hospitalization for atrial fibrillation, acute myocardial infarction, intracranial bleed, stroke, pulmonary embolism, cardiogenic shock, cardiac arrest, and HF. A composite outcome was also analyzed that included any MACCE or mortality.

Statistical Analysis

Baseline patient characteristics were reported as frequencies (percentages) for categorical data and as means (SD) for continuous variables. Multivariable logistic regression was used to examine factors associated with 90-day and 1-year mortality. Results were presented as odds ratios (ORs) and 95% CI. Unadjusted event rates were reported for each outcome using the number of patients with the given event as numerator and person-years (time to first event, death, or end of enrollment) as denominator. Cox proportional hazard regressions with multivariable adjustment were used to compare ACHDHF– to ACHDHF+ index hospitalizations for each outcome. The Fine and Gray method was used to consider death as a competing risk when assessing nonfatal outcomes.[13] Results were presented as hazard ratios (HRs) and 95% CI. A 2-sided *P* value <0.05 was considered statistically significant for all tests. All models included covariates discussed previously. All analyses were conducted using SAS Enterprise Guide 7.1 (SAS Institute, Cary NC) and Stata 16.0 (Stata Corp, College Station TX). Holly K. Van Houten and C. Xiaoxi Yao had full access to all data in the study and take responsibility for its integrity and the data analysis.

Subgroup Analyses

Subgroup analyses included stratification by ACHD type (simple versus complex, single ventricle versus other), age (<45 years or 45+ years), sex (male versus female), and race (non-White versus White).

RESULTS

During the study period (January 2010–December 2020), 26 454 patients with ACHD were hospitalized (Figure 1). The mean age of hospitalized patients with ACHD was 51.9±14.1 years and 45.7% were female. Among ACHD hospitalized patients, 5826 patients were hospitalized with HF (ACHDHF+). The mean follow-up period of 2.23±2.19 years. Whereas the total number of ACHD hospitalizations remained stable across the study period, HF hospitalizations increased significantly, rising from 6.6% in 2010 to 14.0% of all ACHD hospitalizations in 2020 (*P* value for trend<0.0001) (Figure 2). Compared with patients with ACHDHF–, patients with ACHDHF+ were older, and more likely to be male, Black, and Medicare Advantage recipients and to have a higher burden of comorbidities including arrhythmia (45.1%), diabetes (32.3%), renal failure (16.0%), pulmonary hypertension (13.5%), liver disease (7.9%), and anemia (6.8%) (all *P*<0.0001) (Table 1). There was no significant difference in the proportion of patients with Fontan/single ventricle hospitalized with and without HF (*P*=0.058). Patients with ACHDHF+ were more likely to be seen in a cardiology clinic within 30 days before hospitalization compared with the cohort with ACHDHF– (23.3% versus 14.8%, *P*<0.0001). The top 3 reasons for admission in the cohort with ACHDHF– were organ failure (24.8%), atrial arrhythmias (16.9%), and ACHD surgery (15.6%).

All-Cause Mortality

The unadjusted mortality was significantly higher for ACHDHF+ patients (ACHDHF+ 7.04 per 100 person-years versus ACHDHF– 2.12 per 100 person-years). The presence of renal failure, liver disease, diabetes, hypotension, pulmonary hypertension, single ventricle circulation, or age 55 to 70 years was associated with higher 90-day and 1-year mortality. For all hospitalized patients with ACHD (with and without HF), admission for ACHD surgery and cardiology office visit 30 days before hospitalization were associated with significantly lower risk of 90-day and 1-year mortality (Table 2).

All-cause mortality risk was significantly higher for patients with ACHDHF+ compared with ACHDHF– patients when adjusted for baseline patient characteristics and comorbidities (HR, 1.86 [95% CI, 1.67–2.07], *P*<0.001) (Figure 3A; Table 3). In subgroup analysis, the excess HF mortality risk was greater in patients aged <45 years compared with patients ≥45 years (HR, 4.04 [95% CI, 2.90–5.63] versus 1.77 [95% CI, 1.59–1.97]; *P*<0.001). There was no difference in all-cause mortality based on sex, race or ethnicity, single ventricle circulation, or anatomical complexity of CHD (Table S2).

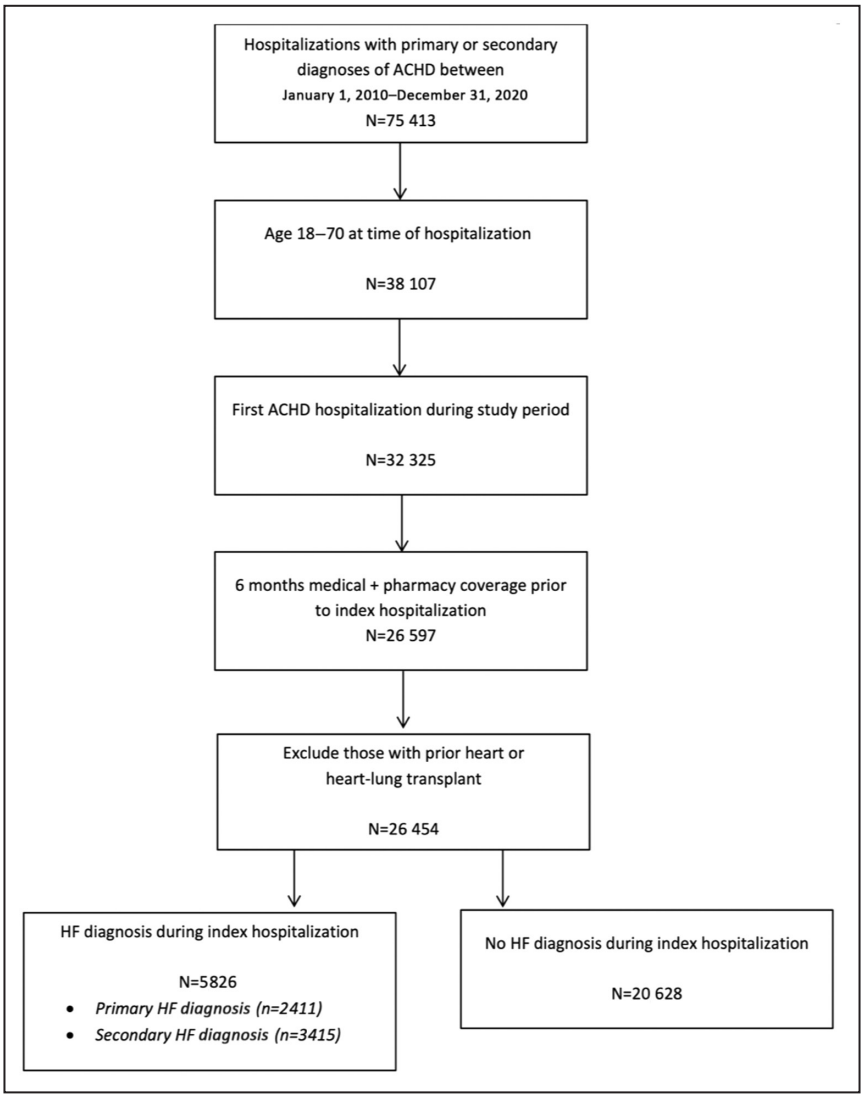

Figure 1. Flow chart for patient selection.
ACHD indicates adult congenital heart disease; and HF, heart failure.

Major Adverse Cardiac and Cerebrovascular Events

Patients with ACHDHF+ had a higher rate of MACCE compared with patients with ACHDHF– (28.26 per 100 person-years versus 9.04 per 100 person-years). Among the group with ACHDHF+, 2220 (38.0%) experienced a MACCE. This was most commonly due to recurrent HF (1176, 20.0%), atrial fibrillation (970, 17.0%), stroke (437, 19.7%), myocardial infarction (296, 5.1%), and cardiac arrest (217, 3.7%). HF hospitalization was associated with MACCE risk (HR, 1.73 [95% CI, 1.63–1.83], $P<0.001$) (Figure 3B). The excess MACCE risk associated with HF hospitalization was greater in patients aged <45 years (HR, 3.14 [95% CI, 2.68–3.69], $P<0.001$) and in female patients (HR, 1.99 [95% CI, 1.82–2.17], $P<0.001$)]. Patients aged <45 years had higher risk of recurrent HF, atrial fibrillation, intracranial hemorrhage, stroke, and cardiac arrest. Female patients had higher risk of atrial fibrillation and recurrent HF. There was no difference in composite MACCE events based on race or ethnicity, single ventricle circulation, or anatomical complexity of CHD (Tables S3–S11).

All-Cause Readmission

Patients with ACHDHF+ were almost twice as likely to be readmitted to hospital (ACHDHF+ 45.30 per 100 person-years versus ACHDHF– 23.42 per 100 person-years). Multivariable Cox regression analysis demonstrated that HF hospitalization was associated with higher risk of all-cause readmission (HR, 1.26 [95% CI, 1.20–1.32], $P<0.001$) (Figure 3C) (Table 3). The excess risk of all-cause readmission associated with HF hospitalization was greater in patients aged <45 years on compared with patients ≥45 years (HR, 1.54 [95%

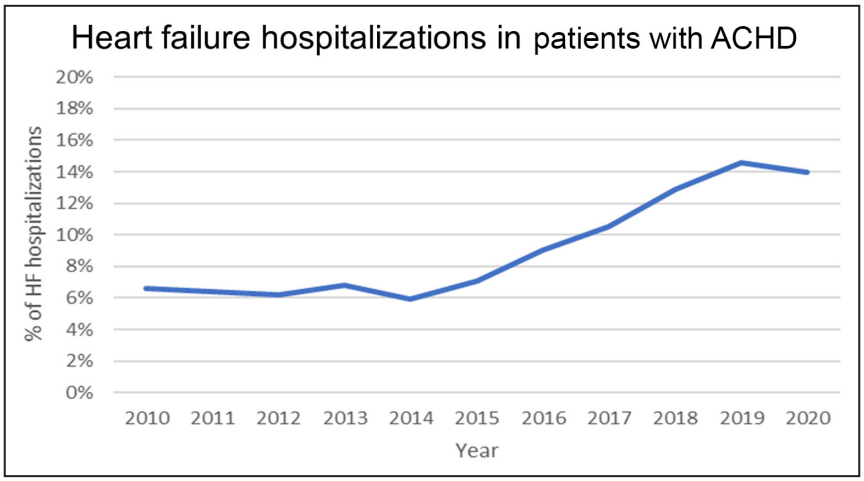

Figure 2. Graph demonstrating increased rate of heart failure hospitalizations in adult patients with congenital heart disease.
ACHD indicates adult congenital heart disease; and HF, heart failure.

CI, 1.36–1.74], *P*<0.001). There was no difference in the risk of all-cause readmission based on sex, race or ethnicity, single ventricle circulation, or anatomical complexity of CHD (Table S12).

All-Cause Emergency Department Visits

Patients with ACHDHF+ had a higher rate of ED visits (ACHDHF+ 45.71 per 100 person-years versus ACHDHF– 34.43 per 100 person-years). HF admission was associated with modestly lower risk of ED visits (HR, 0.95 [95% CI, 0.91–0.99], *P*<0.023) (Figure 3D; Table 3). In subgroup analysis, there was no difference in risk of all-cause ED visits based on age, sex, race or ethnicity, single-ventricle circulation, or anatomical complexity of CHD (Table S13).

Postacute Care Use

Patients with ACHDHF+ had a higher rate of postacute care use (ACHDHF+ 2.20 per 100 person-years versus ACHDHF– 1.02 per 100 person-years). HF admission was associated with higher postacute care use (HR, 1.56 [95% CI, 1.32–1.85], *P*<0.001) (Figure 3E; Table 3). In subgroup analysis, the excess postacute care use risk associated with HF hospitalization was higher in patients aged <45 years (HR, 3.31 [95% CI, 2.19–5.00], *P*<0.001) and in patients with single-ventricle circulation (HR, 9.82 [95% CI, 2.01–47.97], *P*=0.022). There was no difference in postacute care based on sex, race or ethnicity, or anatomical complexity of CHD (Table S14).

DISCUSSION

This study confirms a sharp rise in the number of patients with ACHD being hospitalized in the United States over the past decade for HF. We build on our prior research[7] by demonstrating a sustained increase in mortality risk extending out to 1 year following hospitalization for HF. This heightened mortality risk is especially important for younger patients with ACHD (<45 years), those with coexistent renal failure, liver disease, diabetes, or pulmonary hypertension. MACCE risk is extraordinarily high with 38% of patients with ACHD experiencing a major cardiovascular complication in the first year following hospitalization. Recurrent HF, atrial fibrillation, and stroke are especially common representing modifiable treatment targets for lowering cardiovascular risk. Health resource use is also high with evidence that patients with ACHD engaged in cardiology care have lower mortality risk following hospitalization (Figure 4). We show that patients with ACHD can no longer be regarded as an emerging HF subgroup but one that has fully emerged with a high burden of HF and an urgent need for safe and effective care pathways tailored to their needs.

Survival of patients with ACHD has improved due to significant advances in surgical and medical care, with up to 85% of patients living up to 40 years.[14] Several retrospective studies have reported HF to be the leading cause of mortality in patients with ACHD.[3,4,15,16] With up to 61% of patients with ACHD being lost to specialist care by age 18,[17] there is a risk of selection bias in these prior studies, with limited applicability of the risk estimates and outcomes to the broader population with ACHD, including the 27% of patients being seen outside specialist ACHD centers.[18] By being inclusive of the broader patient community with ACHD, population-based studies overcome these limitations, leading to more accurate estimates of disease incidence and outcomes.

Using a database capturing all Canadians with CHD in Quebec, Wang et al[19] reported HF hospitalizations

Table 1. Baseline Characteristics

No.	No heart failure 20628	Heart failure 5826	Overall 26454	*P* value
Age, y				
Mean (SD)	50.5 (14.4)	57.1 (11.6)	51.9 (14.1)	<0.0001
Median	54	60	55	
Q1, Q3	39.0, 62.0	52.0, 66.0	42.0, 64.0	
Range	18.0–70.0	18.0–70.0	18.0–70.0	
Age groups				
18–24 y	1158 (5.6%)	122 (2.1%)	1280 (4.8%)	<0.0001
25–34 y	2692 (13.1%)	261 (4.5%)	2953 (11.2%)	
35–44 y	2759 (13.4%)	423 (7.3%)	3182 (12.0%)	
45–54 y	4059 (19.7%)	1003 (17.2%)	5062 (19.1%)	
55–64 y	6085 (29.5%)	2181 (37.4%)	8266 (31.2%)	
65–70 y	3875 (18.8%)	1836 (31.5%)	5711 (21.6%)	
Sex, n (%)				
Female	9814 (47.6%)	2274 (39.0%)	12088 (45.7%)	<0.0001
Male	10814 (52.4%)	3552 (61.0%)	14366 (54.3%)	
Race or ethnicity, n (%)				
Unknown	650 (3.2%)	200 (3.4%)	850 (3.2%)	<0.0001
Asian	548 (2.7%)	138 (2.4%)	686 (2.6%)	
Black	2055 (10.0%)	877 (15.1%)	2932 (11.1%)	
Hispanic	1850 (9.0%)	430 (7.4%)	2280 (8.6%)	
White	15525 (75.3%)	4181 (71.8%)	19706 (74.5%)	
Region, n (%)				
Midwest	6303 (30.6%)	1700 (29.2%)	8003 (30.3%)	<0.0001
Northeast	2579 (12.5%)	784 (13.5%)	3363 (12.7%)	
South	8574 (41.6%)	2672 (45.9%)	11246 (42.5%)	
West/unknown*	3172 (15.4%)	670 (11.5%)	3842 (14.5%)	
Health plan, n (%)				
Commercial	15622 (75.7%)	3269 (56.1%)	18891 (71.4%)	<0.0001
Medicare Advantage	5006 (24.3%)	2557 (43.9%)	7563 (28.6%)	
Index hospitalization year, n (%)				
2010	1918 (9.3%)	382 (6.6%)	2300 (8.7%)	<0.0001
2011	1882 (9.1%)	374 (6.4%)	2256 (8.5%)	
2012	1797 (8.7%)	361 (6.2%)	2158 (8.2%)	
2013	1754 (8.5%)	399 (6.8%)	2153 (8.1%)	
2014	1503 (7.3%)	343 (5.9%)	1846 (7.0%)	
2015	1582 (7.7%)	415 (7.1%)	1997 (7.5%)	
2016	1793 (8.7%)	523 (9.0%)	2316 (8.8%)	
2017	2003 (9.7%)	611 (10.5%)	2614 (9.9%)	
2018	2195 (10.6%)	753 (12.9%)	2948 (11.1%)	
2019	2184 (10.6%)	852 (14.6%)	3036 (11.5%)	
2020	2017 (9.8%)	813 (14.0%)	2830 (10.7%)	
Heart failure (index hospitalization), n (%)	0 (0.0%)	5826 (100.0%)	5826 (22.0%)	<0.0001
ACHD surgery (index hospitalization), n (%)	3212 (15.6%)	1141 (19.6%)	4353 (16.5%)	<0.0001
ACHD type, n (%)				
Single ventricle	206 (1.0%)	75 (1.3%)	281 (1.1%)	0.0577

(*Continued*)

Table 1. Continued

No.	No heart failure	Heart failure	Overall	*P* value
	20628	5826	26454	
Complex	3846 (18.6%)	1359 (23.3%)	5205 (19.7%)	<0.0001
Comorbidities, n (%)				
Cardiac arrhythmia	4823 (23.4%)	2629 (45.1%)	7452 (28.2%)	<0.0001
Anemia	820 (4.0%)	397 (6.8%)	1217 (4.6%)	<0.0001
Renal failure	1032 (5.0%)	934 (16.0%)	1966 (7.4%)	<0.0001
Liver disease	1080 (5.2%)	458 (7.9%)	1538 (5.8%)	<0.0001
Diabetes	3567 (17.3%)	1884 (32.3%)	5451 (20.6%)	<0.0001
Hypotension	58 (0.3%)	41 (0.7%)	99 (0.4%)	<0.0001
Pulmonary hypertension	650 (3.2%)	786 (13.5%)	1436 (5.4%)	<0.0001
Cardiology office visit (prior 30 days)	3042 (14.8%)	1355 (23.3%)	4397 (16.6%)	<0.0001
CHA_2DS_2-VASc score groups				
0–1	10451 (50.7%)	1473 (25.3%)	11924 (45.1%)	<0.0001
2–3	7219 (35.0%)	2239 (38.4%)	9458 (35.8%)	
4+	2958 (14.3%)	2114 (36.3%)	5072 (19.2%)	
Index hospitalization				
Primary diagnosis of HF	0 (0.0%)	2411 (41.4%)	2411 (9.1%)	<0.0001
Any diagnosis of HF	0 (0.0%)	5826 (100.0%)	5826 (22.0%)	<0.0001
ACHD surgery	3212 (15.6%)	1141 (19.6%)	4353 (16.5%)	<0.0001
Atrial fibrillation/flutter	3492 (16.9%)	2290 (39.3%)	5782 (21.9%)	<0.0001
Cardiac arrest	338 (1.6%)	293 (5.0%)	631 (2.4%)	<0.0001
Cardiogenic shock	245 (1.2%)	513 (8.8%)	758 (2.9%)	<0.0001
Supraventricular tachycardia	592 (2.9%)	297 (5.1%)	889 (3.4%)	<0.0001
Ventricular tachycardia	867 (4.2%)	733 (12.6%)	1600 (6.0%)	<0.0001
Hemodialysis	98 (0.5%)	115 (2.0%)	213 (0.8%)	<0.0001
Ventilation	686 (3.3%)	389 (6.7%)	1075 (4.1%)	<0.0001
Organ failure	5110 (24.8%)	2864 (49.2%)	7974 (30.1%)	<0.0001
Extracorporeal membrane oxygenation	27 (0.1%)	61 (1.0%)	88 (0.3%)	<0.0001
Ventricular assist device	*	*	93 (0.4%)	<0.0001

Data are presented as n (%) unless otherwise indicated. ACHD indicates adult congenital heart disease; and HF, heart failure.
*West and unknown were collapsed as there were <11 patients in the unknown category.

in 1827 (12.2%) of 14982 patients with ACHD aged ≥40 years. Almost one quarter (23%) of patients with ACHD with HF hospitalization died within 1 year of hospitalization, yielding a 1-year mortality HR of 6.01 (95% CI, 4.02–10.72). The dominant predictor of mortality was kidney dysfunction. In a study of patients with ACHD represented in administrative health data sets from the Canadian province of Ontario, Tsang et al identified HF hospitalizations in 4450 (13.6%) of 32642 patients with ACHD aged >18 years.[20] Patients with ACHD and HF experienced high 30-day and 1-year mortality with adjusted HRs of 4.68 (95% CI, 4.06–5.43) and 3.87 (95% CI, 3.77–4.92), respectively. Comparing patients with HF with and without ACHD, Tsang et al[20] demonstrated higher mortality for those with ACHD, particularly those with defects of great complexity. As for the Quebec study, mortality in patients with ACHD and HF was highest in the first year after HF hospitalization. Perhaps not surprisingly, the Quebec study, which included only patients with ACHD aged ≥40 years, had the highest mortality risk compared with the Ontario study and this analysis.

The current study expands our knowledge of ACHD HF epidemiology in several ways. It is the first study of its kind to quantify HF morbidity and mortality risk among patients with ACHD living in the United States. Second, it is the largest population-based study to describe the profile and outcomes of patients with ACHD and HF before, during, and after HF hospitalization. We confirm a high prevalence of HF with just over one fifth (22%) of patients with ACHD experiencing their first hospitalization for HF within the study period. Third, the study confirms the presence of health disparities with patients who are older, Black, male, and Medicare Advantage health insurance recipients, being at increased risk for

Table 2. Results of Logistic Regression Analysis to Determine Predictors of Mortality

	Mortality Within 90 days		Mortality Within 1 year	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Age groups				
18–24 y	ref	ref	ref	ref
25–34 y	0.95 (0.52–1.75)	0.873	1.18 (0.66–2.10)	0.572
35–44 y	0.78 (0.42–1.46)	0.441	1.26 (0.72–2.22)	0.418
45–54 y	1.19 (0.68–2.10)	0.544	1.57 (0.92–2.69)	0.098
55–64 y	1.53 (0.88–2.66)	0.135	2.18 (1.29–3.68)	0.004
65–70 y	1.67 (0.94–2.99)	0.082	1.89 (1.10–3.26)	0.022
Sex				
Male	ref	ref	ref	ref
Female	1.12 (0.95–1.32)	0.190	1.02 (0.89–1.16)	0.765
Race or ethnicity				
White	ref	ref	ref	ref
Asian	1.07 (0.64–1.80)	0.786	1.09 (0.72–1.65)	0.677
Black	0.96 (0.76–1.21)	0.701	0.99 (0.83–1.19)	0.942
Hispanic	1.02 (0.76–1.36)	0.912	0.88 (0.69–1.12)	0.297
Unknown	1.36 (0.92–2.02)	0.120	1.42 (1.05–1.94)	0.025
Region				
Midwest	ref	ref	ref	ref
Northeast	0.98 (0.75–1.29)	0.903	0.91 (0.73–1.12)	0.291
South	1.26 (1.03–1.52)	0.021	1.11 (0.95–1.29)	0.240
West/unknown	1.28 (0.98–1.67)	0.066	1.14 (0.92–1.42)	0.219
Health plan				
Commercial	ref	ref	ref	ref
Medicare Advantage	2.03 (1.65–2.51)	<0.001	3.16 (2.68–3.74)	<0.001
Index hospitalization year				
2010	ref	ref	ref	ref
2011	1.07 (0.72–1.58)	0.746	0.85 (0.62–1.17)	0.342
2012	0.87 (0.57–1.32)	0.505	0.82 (0.59–1.14)	0.259
2013	0.89 (0.59–1.34)	0.569	0.87 (0.64–1.20)	0.425
2014	0.99 (0.66–1.50)	0.968	0.80 (0.57–1.11)	0.199
2015	0.58 (0.37–0.91)	0.018	0.59 (0.42–0.83)	0.003
2016	0.78 (0.53–1.16)	0.219	0.63 (0.46–0.86)	0.005
2017	0.59 (0.40–0.87)	0.009	0.55 (0.41–0.74)	<0.001
2018	0.71 (0.49–1.03)	0.069	0.57 (0.43–0.77)	<0.001
2019	0.71 (0.49–1.03)	0.071	0.58 (0.44–0.78)	<0.001
2020	0.69 (0.48–1.00)	0.052	0.53 (0.39–0.71)	<0.001
Heart failure (index hospitalization)	1.89 (1.58–2.25)	<0.001	1.94 (1.69–2.23)	<0.001
ACHD surgery (index hospitalization)	0.63 (0.47–0.83)	0.001	0.49 (0.39–0.63)	<0.001
ACHD type				
Single ventricular	3.46 (1.85–6.46)	0.001	3.51 (2.10–5.85)	<0.001
Complex	0.75 (0.60–0.93)	0.010	0.82 (0.70–0.97)	<0.001
Comorbidities				
Cardiac arrhythmia	1.04 (0.87–1.24)	0.651	1.10 (0.96–1.27)	0.191
Anemia	1.18 (0.89–1.56)	0.259	1.24 (1.00–1.54)	0.050
Renal failure	1.55 (1.24–1.93)	<0.001	1.73 (1.46–2.05)	<0.001

(*Continued*)

Table 2. Continued

	Mortality Within 90 days		Mortality Within 1 year	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Liver disease	1.94 (1.54–2.45)	<0.001	2.00 (1.66–2.41)	<0.001
Diabetes	1.27 (1.04–1.54)	0.018	1.20 (1.03–1.40)	0.025
Hypotension	2.62 (1.33–5.12)	0.005	2.28 (1.27–4.08)	0.005
Pulmonary hypertension	1.58 (1.23–2.03)	<0.001	1.66 (1.36–2.02)	<0.001
Cardiology office visits (prior 30 d)	0.62 (0.49–0.78)	<0.001	0.69 (0.58–0.83)	<0.001
CHA_2DS_2-VASc score groups				
0–1	ref	ref	ref	ref
2–3	0.98 (0.78, 1.23)	0.843	0.96 (0.80, 1.15)	0.649
4+	1.11 (0.83, 1.49)	0.491	1.14 (0.91, 1.44)	0.252

ACHD indicates adult congenital heart disease; and OR, odds ratio.

HF requiring hospitalization. Moreover, we demonstrate major comorbidities are common and the presence of arrhythmia, diabetes, anemia, and end-organ kidney, liver, and pulmonary dysfunction, identifies patients with ACHD at increased risk of HF. HF hospitalization itself substantially increases the risk of mortality and morbidity at the time of hospitalization and in the first year following hospitalization. This risk is especially high in younger patients aged <45 years with ACHD, a finding that has been reported for Canadian patients with ACHD[20] and now replicated here for those living with HF in the United States.

We have previously demonstrated longer length of stay and a 258% increase in hospital charges among patients with ACHD and HF over the past decade.[7] The current study extends this knowledge by demonstrating health resource use remains high post hospital discharge with patients with ACHD and HF being twice as likely as patients with with ACHD without HF to be readmitted with more frequent ED visits and higher postacute care service use. This was especially so for younger patients aged <45 years who were again at increased risk of hospital readmission and postacute care use. These findings are consistent with prior research[20] and speak to the need for specific care pathways to optimize HF care in these patients such that comprehensive management is provided at every stage of patients' HF journey. The care pathways may include early postdischarge follow-up in the cardiology clinic, remote hemodynamic monitoring, nurse-led care management such as medication titration, leveraging wearable technology for remote arrhythmia monitoring, referral to cardiac rehabilitation, social worker assistance in psychosocial care, and early referral to multidisciplinary heart transplant and palliative care teams.

In this study, outpatient visits with a cardiologist within 30 days of hospitalization were associated with lower mortality risk for patients with ACHD with and

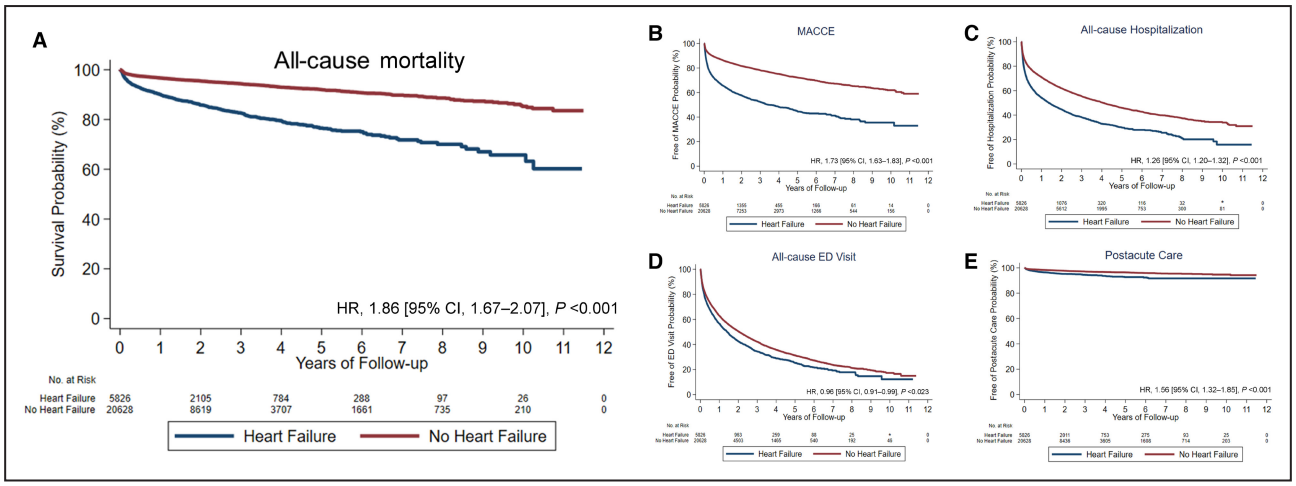

Figure 3. Kaplan–Meier curves comparing all-cause mortality (A), major adverse cardiac and cerebrovascular events (B), all-cause hospitalization (C), all-cause emergency department visits (C), and postacute care service use (E) between adult congenital heart disease patients admitted with and without heart failure. ED indicates emergency department; HR, hazard atio; and MAACE, major adverse cardiac and cerebrovascular events.

Table 3. Results of Cox Regression Analysis Comparing Non–Heart Failure Versus Heart Failure Admissions

	No heart failure (ref)			Heart failure				
	No. with events	Person-years	Event rate per 100	No. with events	Person-years	Event rate per 100	Hazard ratio (95% CI)	*P* value
Outcomes	N=20628			N=5826				
All-cause mortality	1009	47676	2.12	803	11402	7.04	1.86 (1.68–2.07)	<0.001
All-cause readmission	7459	31843	23.42	2917	6439	45.30	1.26 (1.20–1.32)	<0.001
All-cause ED visits	9392	27278	34.43	2845	6224	45.71	0.95 (0.90–0.99)	0.017
All-cause readmission or ED visit	12031	21382	56.27	3917	4346	90.13	1.09 (1.05–1.13)	<0.001
Postacute care	476	46748	1.02	242	11010	2.20	1.56 (1.32–1.85)	<0.001
Any MACCE	3679	40680	9.04	2220	7855	28.26	1.73 (1.63–1.83)	<0.001
Atrial fibrillation	1400	44816	3.12	970	9747	9.95	1.68 (1.53–1.84)	<0.001
Myocardial infarction	430	46931	0.92	296	10990	2.69	1.57 (1.34–1.85)	<0.001
Intracranial bleed	304	47215	0.64	113	11283	1.00	0.93 (0.73–1.18)	0.548
Stroke	1357	45177	3.00	437	10790	4.05	0.85 (0.75–0.95)	0.006
Pulmonary embolism	354	47028	0.75	135	11196	1.21	1.14 (0.91–1.43)	0.248
Cardiogenic shock	57	47604	0.12	143	11279	1.27	6.73 (4.78–9.49)	<0.001
Cardiac arrest	214	47496	0.45	217	11276	1.92	2.33 (1.88–2.90)	<0.001
Heart failure	970	46057	2.11	1176	9623	12.22	2.97 (2.70–3.28)	<0.001
Any MACCE or mortality	4190	40678	10.30	2523	7855	32.12	1.77 (1.68–1.87)	<0.001

Death was used as a competing risk in all models in which mortality was not an end point. All cause 1-year mortality was assessed in this model.
ED indicates emergency department; and MAACE, major adverse cardiac and cerebrovascular events.

without HF. Using the Quebec CHD database, Mylotte et al[18] examined referral rates to specialized ACHD and ACHD patient mortality rates between 1990 and 2005. Following the release of ACHD guidelines[21,22] recommending specialist care, there was a significant increase in referral to ACHD centers and a parallel reduction in ACHD mortality (HR, 0.78 [95% CI, 0.65–0.94]). Interpreting recent cardiology clinic visits as an indicator of health care engagement, our findings provide further evidence for specialist care being important for improving health outcomes in patients with ACHD.

There are limitations to the current study including those inherent to retrospective study design such as lack of causal association and unmeasured confounders. We, and others,[23,24] have reported limitations of administrative data sets in identifying ACHD diagnosis with reported misclassification rate up to 23%.[25] This may be heightened in cases in which 2 different diagnoses are of equal importance for case ascertainment (ACHD, HF), but only 1 can be listed as the primary diagnosis at the time of hospitalization. Inherent differences not captured in the OptumLabs Data Warehouse data set such as New York Heart Association Class, ejection fraction, and B-type natriuretic peptide, or cause of death, further limit our ability to fully explore factors that are important for ACHD HF outcomes. The cardiology clinic visit data could not differentiate ACHD- versus non–ACHD-trained cardiologists. There are limitations to generalizability of the study results as patients without commercial or Medicare insurance who did not have 6 months of medical and pharmacy coverage before index hospitalization would likely have vastly different outcomes. We also have limited data on social determinants of health. We have previously demonstrated patients with ACHD hospitalized in high-volume ACHD centers are more likely to receive guideline-concordant HF treatment with greater access to invasive hemodynamic evaluation, cardiac resynchronization therapy, and mechanical circulatory support.[7] Because the current data set focuses on individuals receiving care and not the centers providing it, we were unable to examine the impact of high- versus low-volume ACHD center care in this study. Even with these limitations, we believe that our findings are consistent with and build upon the few studies to date reporting population-level health outcomes among patients with ACHD hospitalized with HF.

CONCLUSIONS

Patients with ACHD can no longer be regarded as an emerging HF subgroup but one that has fully emerged with a high burden of HF and an urgent need for safe and effective care pathways tailored to their needs. Young adults living with CHD in the United States are at increased risk of death and cardiovascular complications following hospitalization for HF. Those engaged in cardiology care before hospitalization have lower mortality risk, reinforcing the importance of specialist care for achieving optimal health outcomes among adults living with CHD.

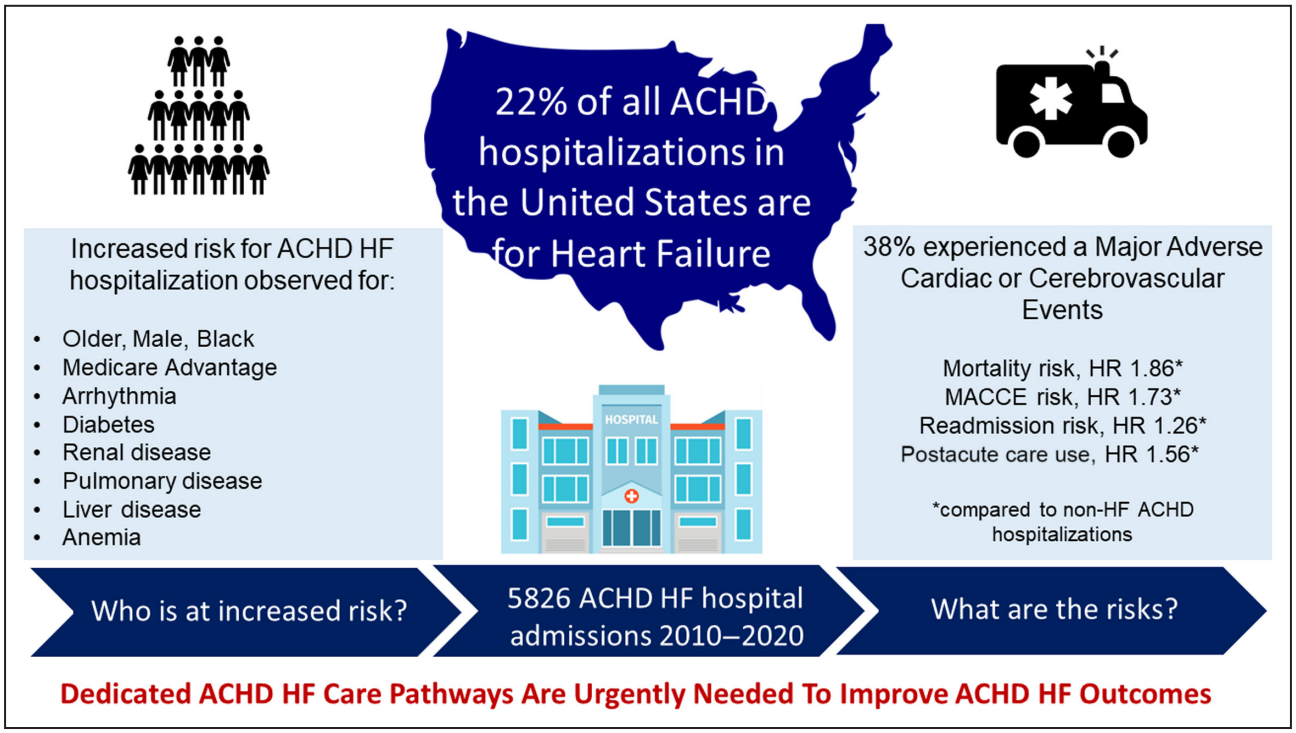

Figure 4. Effect of heart failure hospitalization on long-term outcomes in adults with congenital heart disease.
ACHD indicates adult congenital heart disease; HF, heart failure; HR, hazard ratio; and MACCE, major adverse cardiac and cerebrovascular events.

ARTICLE INFORMATION

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Disclosures

None.

Supplemental Material

Tables S1–S14.

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