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RESEARCH ARTICLE

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Describing characteristics of adults with and without congenital heart defects hospitalized with COVID-19

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Abstract

Background: We sought to describe patient characteristics in adults with and without congenital heart defects (CHDs) during hospitalization for COVID-19.

Methods: We analyzed data collected by Optum®, a nationally representative database of electronic medical records, for 369 adults with CHDs and 41,578 without CHDs hospitalized for COVID-19 between January 1, 2020, and December 10, 2020. We used Poisson regression to describe and compare epidemiologic characteristics, heart-related conditions, and severe outcomes between these two groups.

Results: The distributions of many epidemiologic characteristics were similar between the two groups, but patients with CHDs were significantly more likely to be current or former smokers compared to patients without CHDs (risk ratio [RR]: 1.5, 95% confidence interval [CI]: 1.2, 1.8). Patients with CHDs were also significantly more likely to have heart failure, stroke, acute arrhythmia, myocardial injury, acute pulmonary hypertension, venous thromboembolism, and obesity documented at the time of the COVID-19 hospitalization (RR range: 1.5–4.7) but not respiratory failure. Patients with CHDs (7 days) had a significantly longer median length of stay than those without CHDs (5 days; $p < .001$) and were significantly more likely to have an intensive care unit (ICU) admission (RR: 1.6, 95 CI: 1.2–1.9).

Conclusions: Our description of patients among a large population improves our understanding of the clinical course of COVID-19 among adults with CHDs. Adults with CHD appear to be at greater risk for more severe CHD, including greater risk of ICU admission and longer length of hospital stays.

KEYWORDS

congenital heart disease, COVID-19, epidemiology, heart defects, outcomes

1 | INTRODUCTION

Congenital heart defects (CHDs) are among the most common birth defect, present in ~1% of births (Wu, He, & Shao, 2020) and ~0.4% of adults living in the United States (Marelli, Therrien, Mackie, Ionescu-Ittu, &

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Pilote, 2009). As a result of advancements in CHD screening and treatment, the number of individuals with CHDs surviving to adulthood is increasing (Ogunjimi, Haiduc, & Harky, 2021), and these defects are associated with increased morbidity and mortality throughout adult life (Gilboa, Salemi, Nembhard, Fixler, & Correa, 2010; Gurvitz et al., 2020; Oechslin, Harrison, Connelly, Webb, & Siu, 2000; Verheugt et al., 2010; Warnes et al., 2001).

COVID-19 can have numerous cardiac sequelae in the general population (Driggin et al., 2020; Huang et al., 2020; Long, Brady, Koyfman, & Gottlieb, 2020) and is thought to exacerbate existing complications among individuals with acquired heart disease (Li et al., 2020; Zhou et al., 2020). It has been hypothesized that the cardiovascular consequences of COVID-19 may be particularly severe among adults with CHDs (Gallego, Rupert-Repilado, & Schwerzmann, 2020; Radke, Frenzel, Baumgartner, & Diller, 2020). However, the relative rarity of CHDs has made it challenging to study the potential impacts of COVID-19 infection among adults with CHDs. Most previous reports describing outcomes among adults with CHDs and COVID-19 have suggested that COVID-19 outcomes among adults with CHDs may be commensurate with the general population, or possibly incrementally worse (Broberg et al., 2021; Lewis et al., 2020; Sabatino et al., 2020; Schwerzmann et al., 2021). Because most of these reports have lacked a comparison group (i.e., patients without CHDs) and have involved small numbers of patients with CHDs, many important questions remain. Thus, we sought to use a large, nationally representative database of electronic medical records (EMR) to describe and compare differences in characteristics between adults with and without CHDs hospitalized for COVID-19.

2 | METHODS

2.1 | Data source and study population

The study data set was derived from an EMR database maintained by Optum® for the purpose of timely COVID-19 surveillance and research. The Optum COVID-19 data set was provided by Optum to the University of Texas Center for Health Care Data, University of Texas Health Science Center (UTHealth) School of Public Health, and was managed in accordance with Optum customer data use agreements. Clinical and medical administrative data, including claims and remittance data and practice encounter history, were pulled for all patients who receive care from a large group of inpatient and ambulatory healthcare provider organizations, both public and private, across the United States. Information was processed, normalized, and standardized across the continuum of care from both acute inpatient stays and outpatient visits. Optum data elements included demographics, medications prescribed and administered, lab results, vital signs, other observable measurements, clinical and inpatient stay administrative data, and coded diagnoses and procedures. Information on demographics, laboratory results, treatment details, COVID-19 test results, COVID-related and un-related encounters, and outcomes for patients with documentation of COVID-19 testing was available through the de-identified database, during multiple points of care from January 1, 2020, to the study end date, December 10, 2020.

The specific subset of individuals included in the study was adults hospitalized for COVID-19 for at least 24 hours during the study period, with or without a CHD diagnosis. A positive COVID-19 status was assigned based on laboratory records for molecular diagnostic testing. Results from antigen and antibody tests were not considered. Among COVID-19 positive cases, we restricted our analyses to adult (≥18 years old) patients with COVID-19 hospitalizations, defined as an inpatient hospital admission with admission and discharge date ranges that included or were within 14 days of the positive COVID-19 test result. The first COVID-19 hospitalization for each patient was used if there was more than one COVID-19 hospitalization for the same patient. CHD diagnoses were identified using *International Classification of Diseases, 9th Revision* (ICD-9) and ICD-10 codes (Table 1)

TABLE 1 Type of congenital heart defect for 369 patients with congenital heart defects hospitalized for COVID-19

Type of congenital heart defect (ICD-9 and ICD-10 codes)	*N* (%)[a]
Atrial septal defect (745.5, Q21.1)	288 (73.5%)
Ventricular septal defect (745.4, Q21.0)	37 (9.4%)
Aortic valve stenosis (746.3, Q23.0)	17 (4.3%)
Coarctation of aorta (747.10, Q25.1)	10 (2.6%)
Patent ductus arteriosus (747.0, Q25.0)	9 (2.3%)
Transposition of great arteries (745.10, 745.11, 745.12, 745.19, Q20.1, Q20.3, Q20.5)	8 (2.0%)
Tetralogy of Fallot (745.2, Q21.3)	7 (1.8%)
Pulmonary valve atresia and stenosis (746.01, 746.02, Q22.0, Q22.1)	5 (1.3%)
Other[b]	11 (2.8%)

[a]Totals may exceed the number of patients with congenital heart defects due to some patients with multiple congenital heart defects.
[b]Rare congenital heart defects: common truncus (745.0, Q20.0), atrioventricular septal defect (745.60, 745.61, 745.69, Q21.2), tricuspid valve atresia and stenosis (746.1, Q22.4), Ebstein's anomaly (746.2, Q22.5), hypoplastic left heart syndrome (746.7, Q23.4), total anomalous pulmonary venous return (747.41, Q26.2).

(Mburia-Mwalili & Yang, 2014). The remaining COVID-19 positive patients without CHDs hospitalized for COVID-19 were used for comparison.

The protocol for this study was approved by the UTHealth Institutional Review Board, and consent was waived given the size of the population and the inability to identify those involved.

2.2 | Statistical analysis

This study is a retrospective, descriptive analysis of adults with and without CHDs hospitalized for COVID-19. We identified the count and proportion of potentially eligible patients at each inclusion step. To visually examine trends over time, we plotted counts of adults with and without CHDs for each month of the study period, separately for COVID-19 testing, positive test results, and hospitalizations. Total counts and proportions were tabulated for each CHD type (e.g., atrial septal defects). Variable counts and percentages were tabulated for several patient characteristics, separately for patients with and without CHDs using a complete case analysis. These variables included age, race/ethnicity, sex, primary insurance status, region, and smoking status. For comparison between these two groups, risk ratios and 95% confidence intervals were calculated for each variable category. The mean age upon admission was also tabulated separately for patients with and without CHDs and compared using a Student's *t* test.

Analyses were repeated for medical conditions documented during the COVID-19 hospitalization using their respective ICD-9 and ICD-10 codes (Appendix A): heart failure, stroke, acute arrhythmia, respiratory failure, myocardial injury, acute pulmonary hypertension, and venous thromboembolism. Similarly, obesity status (yes/no) was determined by ICD-9 and ICD-10 codes documented either during the COVID-19 hospitalization or during any other encounter in the year prior to the COVID-19 hospitalization.

Death (in-hospital and out-of-hospital death) and variables that reflect the severity of COVID-19 treatment/illness during the COVID-19 hospitalization (e.g., ICU admission, ventilation use, and length of stay) were identified, and analyses were repeated for these variables. We examined mortality within three respective time periods: (a) during the month of COVID-19 admission, (b) during the month of COVID-19 admission or the next month, and (c) during or any time after the COVID-19 admission through December 10, 2020. Length of stay was compared between the two groups as a continuous variable, using a Student's *t* test.

We also repeated our analyses of medical conditions and outcomes post hoc for patients with only mild CHDs (atrial septal defects [ASDs], patent ductus arteriosus [PDA], or ventricular septal defects [VSDs]), instead of the full CHD group. All analyses were performed using SAS version 9.4 (Cary, NC).

3 | RESULTS

Between January 1, 2020, and December 10, 2020, data for 3,825,302 adults without CHDs and 20,705 adults with CHDs were available. Of the adults with CHDs, 1,751 had positive COVID-19 molecular diagnostic test results. The proportion of patients with positive COVID-19 results that were hospitalized was higher among those with CHDs (21.1%) compared to those without CHDs (11.9%) (Figure 1). Trends for COVID-19 testing, positive test results, and hospitalization by month were generally similar between adults with and without CHDs (Figure S1a–b). Overall, 369 adults with CHDs and 41,578 without CHDs were hospitalized for COVID-19 (Figure 1). The most frequently observed type of CHD was ASDs ($N = 288$, 73.5%), followed by VSDs ($N = 37$, 9.4%) and aortic valve stenosis ($N = 17$, 4.3%; Table 1).

The distributions of age, race/ethnicity, and sex were similar between patients with and without CHDs (Table 2). However, patients with CHDs were significantly more likely to be "current or former" smokers (risk ratio [RR] = 1.45, 95% CI: 1.18, 1.79) versus never having smoked compared to patients without CHDs. Patients with CHDs were significantly less likely to be uninsured (RR = 0.15, 95% CI: 0.05, 0.48) or have "other" insurance (RR = 0.40, 95% CI: 0.23, 0.68) versus private insurance compared to adults without CHDs. Additionally, patients with CHDs were more likely to be from the Northeast versus South regions compared to patients without CHDs (RR = 1.52, 95% CI: 1.14, 2.03).

Patients with CHDs hospitalized for COVID-19 were significantly more likely than those without CHDs to have seven of the eight medical conditions evaluated, but not respiratory failure (Table 3). This included observed increased risk for heart failure, acute arrhythmia, myocardial injury, acute pulmonary hypertension, venous thromboembolism, and obesity (range of RRs: 1.5–4.7).

We also compared select outcomes during the COVID-19 hospitalization between subjects with and without CHDs (Table 4). Adults with CHDs experienced a significantly increased risk of ICU admission (RR = 1.55, 95% CI: 1.24, 1.94) compared to those without CHDs, though differences between these groups in risk for ventilator support were not observed. The median length of stay was significantly higher among patients

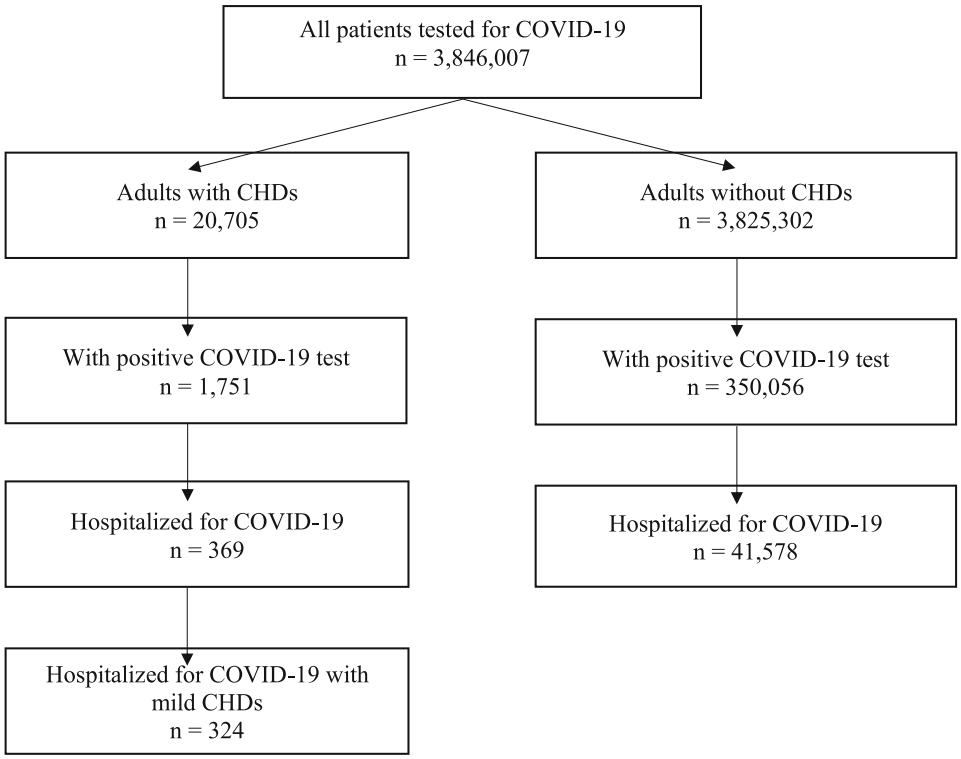

FIGURE 1 Flow diagram outlining the patient inclusion and exclusion criteria

with CHDs (7 days) as compared to those without CHDs (5 days; $p < .001$). There were no differences in the risk of death during hospitalization between the two groups (RR: 1.0, 95% CI: 0.74, 1.34), though patients with CHDs had a modest, but nonsignificant, increase in death during the month of COVID-19 admission or the next month (RR = 1.18, 95% CI: 0.90, 1.54) and death during or at any time after the hospitalization month (RR = 1.21, 95% CI: 0.93, 1.58).

Given the large proportion of patients with only mild CHDs (324/369), we repeated our analyses of medical conditions and outcomes post hoc among this group instead of the full CHD group. The observed associations were similar to the results among the full analytic group across these comparisons, with magnitudes of association that were almost all slightly larger (e.g., RR: 3.2 versus 2.9, respectively, for acute arrhythmia) (Table S1). Further, in these sub-analyses, patients with only mild CHDs had a significantly increased risk of death both during the month of COVID-19 admission or the next month (RR = 1.35, 95% CI: 1.02, 1.78) and during or at any time after the hospitalization month (RR = 1.37, 95% CI: 1.05, 1.80) (Table S2).

4 | DISCUSSION

This descriptive study is among the first to compare adults with and without CHDs who were hospitalized for COVID-19. Our findings imply that adults with CHDs may have higher medical vulnerability to severe COVID-19; thus, CHDs may be candidates for inclusion on the evolving list of underlying medical conditions that may increase risk for severe COVID-19 (Centers for Disease Control and Prevention, 2021). Most prior work in this area has focused on populations of adults with CHDs with COVID-19, without direct comparison to adults without CHDs. As the pandemic continues, better understanding the impact of COVID-19 among adults with CHDs will remain critical to optimizing health outcomes among this important population.

Adults with CHDs are hypothesized to have increased risk for severe COVID-19, particularly in terms of cardiovascular involvement (Magoon, 2020; Ogunjimi et al., 2021; Radke et al., 2020). Given that acquired cardiac disease (e.g., coronary heart disease or heart failure) is associated with severe COVID-19 outcomes among the general population, it has been similarly hypothesized that adults with CHDs—who have potentially impaired and/or vulnerable hearts—may be at risk for worse COVID-19 outcomes (Tan & Aboulhosn, 2020), though the exact mechanisms potentially involved (e.g., exacerbation of heart failure and other cardiovascular and respiratory outcomes (Aladag & Atabey, 2021; Gupta et al., 2020; Russo et al., 2020)) are not understood. While mild CHDs are generally considered to have milder clinical consequences compared to severe CHDs, our findings may

TABLE 2 Characteristics documented at the time of COVID-19 hospitalization among subjects with and without CHDs

Variable	With CHD N (%) ($N = 369$)	Without CHD N (%) ($N = 41,578$)	Risk ratio (95% CI)
Age (years)			
18–49	82 (22.2%)	10,058 (24.2%)	Reference
50–59	68 (18.4%)	6,999 (16.8%)	1.19 (0.86–1.64)
60–69	81 (22.0%)	8,851 (21.3%)	1.12 (0.83–1.52)
≥70	138 (37.4%)	15,670 (37.7%)	1.08 (0.82–1.42)
Mean (standard deviation)	62.09 (17.16)	61.79 (17.94)	p value = .75
Race/ethnicity			
Black	82 (22.2%)	8,354 (20.1%)	1.11 (0.86–1.44)
Asian	10 (2.7%)	982 (2.4%)	1.15 (0.61–2.17)
Non-Hispanic White	183 (49.6%)	20,713 (49.8%)	Reference
Hispanic	26 (7.0%)	2,428 (5.8%)	1.21 (0.80–1.82)
White, ethnicity unknown	16 (4.3%)	1,445 (3.5%)	1.25 (0.75–2.08)
Race other/unknown and ethnicity unknown	52 (14.1%)	7,656 (18.4%)	0.77 (0.57–1.05)
Sex			
Male	198 (53.7%)	21,151 (50.8%)	1.12 (0.91–1.37)
Female	171 (46.3%)	20,400 (49.1%)	Reference
Missing	–	27 (0.06%)	
Smoking status[a]			
Never	182 (49.3%)	22,102 (53.2%)	Reference
Current or former	174 (47.2%)	14,447 (34.7%)	1.45 (1.18–1.79)
Primary insurance			
Medicare	102 (27.6%)	10,635 (25.6%)	1.02 (0.80–1.30)
Medicaid	55 (14.9%)	5,116 (12.3%)	1.14 (0.84–1.54)
Private	187 (50.7%)	19,842 (47.7%)	Reference
Uninsured	3 (0.8%)	2,093 (5.0%)	0.15 (0.05–0.48)
Other	14 (3.8%)	3,775 (9.1%)	0.40 (0.23–0.68)
Missing	8 (2.2%)	117 (0.3%)	
Region			
Midwest	138 (37.4%)	16,035 (38.6%)	1.18 (0.89–1.56)
Northeast	120 (32.5%)	10,824 (26.0%)	1.52 (1.14–2.03)
South	74 (20.1%)	10,171 (24.5%)	Reference
West	30 (8.1%)	3,254 (7.8%)	1.27 (0.83–1.93)
Other/unknown	7 (1.9%)	1,294 (3.1%)	0.74 (0.34–1.61)

[a]Documented in an admission before the COVID-19 hospitalization when missing during the COVID-19 hospitalization ($N = 67$ with CHDs and 6,284 without CHDs). Smoking status was missing for $N = 13$ with CHDs and 5,029 without CHDs.

highlight an increased risk for severe COVID-19 outcomes among patients with mild CHDs, including death and cardiac and respiratory conditions. For example, adults with only mild CHDs hospitalized with COVID-19 had a threefold increased risk of heart failure, acute arrhythmias, and venous thromboembolism and a fourfold increased risk of acute pulmonary hypertension compared to adults without CHDs. Congestive heart failure, atrial arrhythmias, and thrombosis of large pulmonary arteries are also common in adults with an untreated ASD without COVID-19, and there remains a risk of an atrial arrhythmia even after successful closure of the defect, particularly in adults aged >50 years of age (Hoffman, Kaplan, & Liberthson, 2004), including

TABLE 3 Conditions documented at the time of COVID-19 hospitalization among subjects with and without CHDs

Variable	With CHD N (%) ($N = 369$)	Without CHD N (%) ($N = 41{,}578$)	Risk ratio (95% CI)
Heart failure			
Yes	176 (47.7%)	9,048 (21.8%)	3.24 (2.64–3.96)
No	193 (52.3%)	32,530 (78.2%)	Reference
Stroke			
Yes	113 (30.6%)	8,136 (19.6%)	1.80 (1.45–2.25)
No	256 (69.9%)	33,442 (80.4%)	Reference
Acute arrhythmia			
Yes	225 (61.0%)	14,608 (35.1%)	2.86 (2.32–3.52)
No	144 (39.0%)	26,970 (64.9%)	Reference
Respiratory failure			
Yes	207 (56.1%)	23,328 (56.1%)	1.0 (0.81–1.23)
No	162 (43.9%)	18,250 (43.9%)	Reference
Myocardial injury			
Yes	116 (31.4%)	7,066 (17.0%)	2.22 (1.78–2.76)
No	253 (68.6%)	34,512 (83.0%)	Reference
Acute pulmonary hypertension			
Yes	99 (26.8%)	2,936 (7.1%)	4.70 (3.75–5.90)
No	270 (73.2%)	38,642 (92.9%)	Reference
Venous thromboembolism			
Yes	16 (4.3%)	562 (1.4%)	3.24 (1.98–5.32)
No	353 (95.7%)	41,016 (98.6%)	Reference
Obesity[a]			
Yes	99 (30.6%)	9,460 (22.8%)	1.53 (1.23–1.91)
No	225 (69.4%)	32,118 (77.2%)	Reference

[a]Obesity documented during the COVID-19 hospitalization or within the prior year.

adults with previously asymptomatic ASDs. Our data may suggest that COVID-19 might exacerbate these risks. Thus, it seems plausible that these mild CHDs, including some defects without obvious acute symptoms, may be associated with more severe COVID-19 outcomes. Considering that these defects are relatively common and may be undiagnosed, more work is needed to confirm and better understand these associations.

Prior studies have used EMR data collected across international adult CHD (ACHD) clinics ($N = 1{,}044$; Broberg et al., 2021), ACHD centers in Europe ($N = 105$; Schwerzmann et al., 2021), a single clinical center in the United States ($N = 43$; Lewis et al., 2020), and nationwide data from Italy ($N = 72$; Sabatino et al., 2020). Many of these prior studies have focused on comparing outcomes among adults with mild versus severe CHDs, which was not the focus of our analyses. Several smaller case reports and case series of adults with CHDs and COVID-19 have also been described [e.g., $N < 10$ cases; reviewed in Haiduc et al. (2021)].

In contrast to the patient composition of previous studies (26.3% and 39%; Broberg et al., 2021; Schwerzmann et al., 2021), our population had a very high proportion of adults with only mild CHDs (87.8%). ASDs in particular were especially frequent (73.5%). This distribution may reflect differences in patient populations and ascertainment compared to past work. For instance, several prior studies have focused exclusively on centers with ACHD clinics that tend to treat cases with more severe CHDs, whereas these sites may have been underrepresented in our data, which included data from over 700 hospitals but likely had an underrepresentation of children's hospitals or other facilities with specialized CHD treatment capacity compared to prior studies; data were not available to explore this specifically. The true population prevalence of ASDs and other mild (e.g., frequently asymptomatic) CHDs among adults in the United States has been difficult to establish. In a large population-based study of heart failure-related hospitalizations in adults with CHDs, ASDs, VSDs, and/or PDAs

TABLE 4 Outcomes during the COVID-19 hospitalization among subjects with and without CHDs

Variable	With CHD N (%) ($N = 369$)	Without CHD N (%) ($N = 41{,}578$)	Risk ratio (95% CI)
ICU admission			
Yes	110 (29.8%)	8,910 (21.4%)	1.55 (1.24–1.94)
No	259 (70.2%)	32,668 (78.6%)	Reference
Ventilator support			
Yes	109 (29.5%)	11,555 (27.8%)	1.09 (0.87–1.36)
No	260 (70.5%)	30,023 (72.2%)	Reference
Median length of stay in days (standard deviation)	7.0 (11.94)	5.0 (10.29)	p value <.001
Death during the month of COVID-19 admission			
Yes	51 (13.8%)	5,764 (13.9%)	1.0 (0.74–1.34)
No	318 (86.2%)	35,814 (86.1%)	Reference
Death during the month of COVID-19 admission or the next month			
Yes	62 (16.8%)	6,091 (14.6%)	1.17 (0.90–1.54)
No	307 (83.2%)	35,487 (85.4%)	Reference
Death during or any time after the COVID-19 admission[a]			
Yes	67 (18.2%)	6,415 (15.4%)	1.21 (0.93–1.58)
No	302 (81.8%)	35,163 (84.6%)	Reference

[a]Through December 10, 2020.

were present in the majority (54%) of patients (Rodriguez 3rd et al., 2013). However, it is not unusual for ASDs to go undetected among adults (Hoffman et al., 2004), and it may even be that some of these mild lesions were first detected at the time of COVID-19 hospitalization in our patient population.

Overall, patients with CHDs in our study were more likely than those without CHDs to have cardiovascular conditions (heart failure, stroke, acute arrhythmia, myocardial injury, acute pulmonary hypertension, and venous thromboembolism) documented at the time of the COVID-19 hospitalization. We observed fairly similar (though perhaps generally higher) percentages of adults with CHDs with pulmonary hypertension and heart failure compared to at least some of the prior studies (Table S3) but substantially higher rates of respiratory failure (56.1%) and arrhythmias (61.0%) among patients with CHDs compared to earlier findings, which may be at least in part related to the older age of our cohort compared to prior studies (Table S3). With regard to COVID-19 outcomes, the proportions of adults with CHDs (a) admitted to the ICU or (b) with ventilator support were both within the range of prior estimates (6.4–33% and 3.4–30.8%, respectively). However, the observed proportion who died during the month of COVID-19 admission (13.8%) was higher in our study than the range of prior death estimates (2–7%; Table S3), though this might be explained to a certain extent by our older study cohort. A small proportion of adults with severe CHDs died, which was unexpected, though we caution against trying to draw strong conclusions about this given the small number of adults with severe CHDs. It seems possible that there could have been less severe COVID-19 among these compared to other hospitalized individuals (e.g., there may have been a lower threshold for inpatient admission given potential concerns about the severe CHD) and/or that those with severe CHDs hospitalized for COVID-19 may have received better care than others (e.g., due to a concern about the CHD).

In our analyses, patients with CHDs also differed from patients without CHDs with regard to smoking and obesity status. Smoking and obesity are factors that increase risk for severe COVID-19 or COVID-related death, per the Centers for Disease Control and Prevention, and findings must be interpreted in the context of these potentially important differences between the CHD and comparison group. Among data collected prior to the pandemic, those with CHDs tended to have lower rates of smoking than those without CHDs (Engelfriet et al., 2008). One possible explanation for the distributions of smoking and obesity in this study is that our sample of hospitalized patients over-represents (i.e., is enriched for) patients who have multiple risk factors for severe COVID-19 (e.g., smoking and CHD, obesity, and

CHD) because these individuals may be more likely to be hospitalized than those with only one predisposing factor. Still, concerning rates of cigarette smoking (5–28%) among adults with CHDs have been documented (Holbein et al., 2020). Smoking among adults with CHDs may be associated with adverse outcomes such as increased cardiovascular mortality (Engelfriet et al., 2008), more emergency department visits (Agarwal et al., 2016), and coronary heart disease (Bokma et al., 2018). Thus, even in the absence of COVID-19, smoking in adults with CHDs may compound already impaired cardiovascular structure and physiology. Patients with CHDs in our study were also more likely than those without CHDs to be obese during the COVID-19 hospitalization or within the prior year. High rates of obesity among adults with CHDs have been reported (reviewed in (Andonian et al., 2019)), and it is thought that obesity likely adversely influences cardiac outcomes among individuals with CHDs (Andonian et al., 2019).

4.1 | Limitations of the study

We used data collected among hospitals throughout the United States, and there may be differences between our population and some of those in the prior literature. Some prior studies have focused on populations among ACHD clinics (Broberg et al., 2021; Schwerzmann et al., 2021), which likely are enhanced for more severe CHDs compared to our population, which had a relatively low proportion of severe CHDs (e.g., conotruncal defects; Table S3). Further, many previous studies used data from academic medical centers or large volume centers, and these findings may not be generalizable to the general population. The patients in our study were much older (mean 62 years of age) compared to prior studies (e.g., 35–38, Table S3), as not all prior studies have been restricted to adults. Given our data structure, we also could not distinguish between onset of medical conditions during versus before COVID-19 hospitalization, and it is therefore likely that at least some of these conditions developed before SARS-CoV-2 infection and some developed after. However, an early study among adults in the general population from Wuhan, China, reported similar proportions to our reported rates among the adults without CHDs for respiratory failure (54%), heart failure (23%), and acute cardiac injury (17%) following COVID-19 hospitalization (as opposed to before or during hospitalization; Zhou et al., 2020), which may suggest that at least some of these conditions developed after COVID-19 onset (e.g., whether before or during hospitalization) in our study.

Additional limitations of our study should be noted, including our use of secondary EMR data, which was originally collected for clinical rather than research purposes. Our data focus on the time period before the relatively recent widespread availability of COVID-19 vaccines, and confirming these associations in more recent data would shed further light on the generalizability of the results. Our study is descriptive in nature, and additional studies are needed to rule out alternative explanations and establish temporality for observed differences and associations.

5 | CONCLUSION

Given the descriptive nature of our analyses, more targeted, hypothesis testing may also be helpful for future work, and our results may be helpful for forming such hypotheses. Strengths of our study include the large sample of adults hospitalized with COVID-19 for adults with and without CHDs and the availability of an appropriate comparison group without CHDs. Our findings may support future counseling and care for adults with CHDs. For example, if our findings are replicated, there may be implications for clinical guidelines, identification of high-risk individuals, vaccine allocation policies, and better screening for outcomes among this population. Future work, including data among vaccinated patients, may be critical for better understanding this population.

CONFLICT OF INTEREST

There are no industry affiliations to acknowledge.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from Optum. Restrictions apply to the availability of these data, which were used under license for this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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