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ORIGINAL RESEARCH

Impact of Coronavirus Disease 2019 (COVID-19) on Patients With Congenital Heart Disease Across the Lifespan: The Experience of an Academic Congenital Heart Disease Center in New York City

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BACKGROUND: We sought to assess the impact and predictors of coronavirus disease 2019 (COVID-19) infection and severity in a cohort of patients with congenital heart disease (CHD) at a large CHD center in New York City.

METHODS AND RESULTS: We performed a retrospective review of all individuals with CHD followed at Columbia University Irving Medical Center who were diagnosed with COVID-19 between March 1, 2020 and July 1, 2020. The primary end point was moderate/severe response to COVID-19 infection defined as (1) death during COVID-19 infection; or (2) need for hospitalization and/or respiratory support secondary to COVID-19 infection. Among 53 COVID-19-positive patients with CHD, 10 (19%) were <18 years of age (median age 34 years of age). Thirty-one (58%) had complex congenital anatomy including 10 (19%) with a Fontan repair. Eight (15%) had a genetic syndrome, 6 (11%) had pulmonary hypertension, and 9 (17%) were obese. Among adults, 18 (41%) were physiologic class C or D. For the entire cohort, 9 (17%) had a moderate/severe infection, including 3 deaths (6%). After correcting for multiple comparisons, the presence of a genetic syndrome (odds ratio [OR], 35.82; P=0.0002), and in adults, physiological Stage C or D (OR, 19.38; P=0.002) were significantly associated with moderate/severe infection.

CONCLUSIONS: At our CHD center, the number of symptomatic patients with COVID-19 was relatively low. Patients with CHD with a genetic syndrome and adults at advanced physiological stage were at highest risk for moderate/severe infection.

Key Words: adult congenital heart disease ■ congenital heart disease ■ COVID-19 ■ outcomes

Coronavirus disease 2019 (COVID-19) has caused a worldwide pandemic and is responsible for >120 000 deaths in the United States to date, 30 000 of which have been in New York City and the surrounding counties.[1] While corona viruses are known to cause respiratory and gastrointestinal infections in humans,[2] they can also trigger cardiac decompensation. COVID-19 infection, in particular, has been shown to cause life-threatening illness in patients with cardiovascular risk factors[3] and may manifest as myocardial

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For Sources of Funding and Disclosures, see page 8.

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CLINICAL PERSPECTIVE

What Is New?

- Coronavirus disease 2019 (COVID-19) infection has been shown to cause life-threatening illness in patients with cardiovascular risk factors, but the impact of COVID-19 infection on individuals with congenital heart disease remains unknown.
- While individuals with congenital heart disease are typically younger than those with acquired cardiac disease, and less likely to have comorbidities associated with severe COVID-19 infection, it is unclear whether factors unique to the congenital heart disease population are also associated with infection severity.

What Are the Clinical Implications?

- During the height of the COVID-19 pandemic in New York City in March and April of 2020, the number of symptomatic individuals with congenital heart disease and COVID-19 followed at our center was relatively low; however, those with a genetic syndrome and adults at advanced physiological stage were at highest risk for moderate or severe infection.

Nonstandard Abbreviations and Acronyms

COVID-19	coronavirus disease 2019

cell injury, myocarditis, arrhythmias, and cardiac arrest.[4,5] Despite increasing recognition that pre-existing cardiac disease is associated with poor outcomes in the general population, the impact of COVID-19 infection on patients with congenital heart disease (CHD) remains unknown.

Given the heterogeneity implicit in the population with CHD, predicting the response to COVID-19 infection is challenging. Patients with complex congenital heart lesions, both unrepaired and palliated, frequently have concurrent cardiac and pulmonary disease. Because COVID-19 infection has been shown to induce significant pulmonary,[6] cardiac,[7] and endothelial cell dysfunction,[8] such patients may be at particularly high risk for severe complications arising from COVID-19 infection. However, the population with CHD is also typically younger than patients with acquired cardiac disease, with a lower population prevalence of hypertension, diabetes mellitus, and coronary artery disease—risk factors for adverse events during influenza outbreaks[9] and for the current COVID-19 outbreak. As such, we sought to review our experience with COVID-19 in patients with CHD who presented to medical care across the age spectrum during the recent New York City outbreak.

METHODS

Study Population and Inclusion Criteria

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 the corresponding author. Approval from the Columbia University Irving Medical Center Institutional Review Board was obtained before data acquisition and included a waiver of consent. We performed a retrospective study of all individuals with CHD followed at Columbia University Irving Medical Center who presented to medical care and were diagnosed with COVID-19 between March 1 and July 1, 2020. Given the limited availability of viral testing during the study period, individuals were considered COVID-19 positive if they tested PCR positive or if they had a positive household or roommate contact and developed symptoms consistent with COVID-19. Only individuals who came to medical attention via telemedicine, Emergency Department presentation, hospital admission, or direct physician contact were included.

Symptomatic Infections

The primary end point of interest was the incidence of moderate/severe COVID-19 symptomatic infection, defined as death, the need for hospitalization, or the need for new or increased respiratory support. Patients who presented to medical care but who did not meet the definition of moderate/severe symptoms were defined as having mild symptoms. For hospitalized individuals, clinical data were analyzed including inflammatory makers, IL-6 levels, NT-proBNP (N-terminal pro-B-type natriuretic peptide), and high-sensitivity troponin assays. Patient symptoms on presentation were gathered from medical records. Symptom duration was quantified when possible and confirmed with patients. Patients with an indeterminate symptom start date were not included in the analysis of symptom duration.

Exposures of Interest

Clinical variables were defined before data collection and were extracted from the electronic medical record. Variables of interest included demographic and historical data, including CHD diagnosis, CHD surgeries, medical comorbidities, and a history of a genetic syndrome. Obesity was defined as a body mass index ≥30.0 for patients≥18 years of age and as a body mass index ≥95% percentile for patients

<18 years of age. Pre-infection functional status and baseline saturation data were collected from each patient's most recent medical appointment. The latest cardiac surgery for each patient was determined and classified according to the Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STAT) category.[10] Baseline creatinine, hematocrit, and NT-proBNP were collected when possible.

Anatomic Complexity and Physiological Stage

The physiological stage for adult patients with CHD was stratified according to the American College of Cardiology/American Heart Association Adult Congenital Heart Disease Guidelines. Patients were classified as being at Physiological stage C or D if they met the following criteria: New York Heart Association functional class III or greater; moderate or greater valvular stenosis or regurgitation; moderate/severe aortic enlargement; moderate/severe ventricular dysfunction; hypoxemia (pulse oximetry at rest <90%); hemodynamically significant shunt (chamber enlargement distal to shunt and/or Qp:Qs≥1.5:1); arrhythmias (controlled or refractory to treatment); pulmonary hypertension (mean pulmonary artery pressure ≥25 mm Hg); Eisenmenger syndrome; or clinical or laboratory evidence of end-organ dysfunction.[11]

Anatomic complexity was also classified according to the 2018 American College of Cardiology/American Heart Association Adult Congenital Heart Disease Guidelines. Patients were considered to have complex congenital anatomy if they had any of the following: cyanotic heart defects (unrepaired or palliated); status post Fontan procedure; single ventricle physiology; pulmonary atresia; transposition of the great arteries; truncus arteriosus; or abnormalities of atrioventricular and ventriculoarterial connection.

Echocardiographic Data

Echocardiographic data were obtained via historical review of transthoracic echocardiograms read by cardiologists who were board-certified in congenital heart disease. Each patient's most recent, pre-infection echocardiogram was included. Patients were considered to have abnormal ventricular function if either the systemic or pulmonic ventricle had at least mild systolic dysfunction. Right ventricular systolic pressure was obtained when available. Individuals with ≥moderate stenosis or regurgitation of any valve were considered to have significant valvular disease.

Statistical Analysis

Data were expressed as n (%), mean, or median where appropriate. Univariable analyses comparing discrete clinical variables were performed with exact logistic regression, overall and stratified by <18 or ≥18 years of age.[12] Continuous variables of interest were analyzed by standard *t* tests. We corrected for multiple hypothesis testing by assessing a penalty for 10 tests of association with the outcome yielding a corrected significance threshold of 0.005. Statistical analysis was performed with Stata statistical software (version 14.1; Stata Corp, College Station, TX).

RESULTS

We identified 53 individuals with CHD at our medical center who met our definition for COVID-19 infection during the observation period. Symptoms were present in 52 individuals. One asymptomatic patient came to medical attention secondary to concern for potential infection after a family member tested positive. Ten patients (19%) were <18 years of age at the time of diagnosis. The median age of the cohort was 34 years of age. Patient congenital heart diagnoses included 16 (30%) with tetralogy of Fallot or pulmonary stenosis; 10 (19%) with single ventricle physiology status post Fontan palliation; 6 (11%) with shunting defects; 7 (13%) with a congenital valve abnormality; 7 (13%) with atrioventricular canal defects; and 7 (13%) with a different diagnosis (anomalous left coronary off the pulmonary artery, anomalous right coronary artery, coarctation of the aorta, double-chamber right ventricle, congenitally corrected transposition of the great arteries, pulmonary atresia, and D-transposition of the great arteries). Six patients (11%) had pulmonary hypertension (PH) requiring treatment with outpatient pulmonary vasodilator therapy before infection and 4 of these patients had Eisenmenger syndrome. Eight (15%) had genetic syndromes, including 5 (9%) with trisomy 21, 2 (4%) with DiGeorge syndrome and 1 (2%) with VACTERL association. Notably, 4 of the 6 individuals with PH also had genetic syndromes. Among all patients, 6 (11%) had branch pulmonary artery abnormalities requiring prior intervention and 6 (11%) had chronic lung disease (2 with obstructive sleep apnea, 2 with chronic obstructive lung disease, 1 with unilateral pulmonary hypoplasia, and 1 with chronic bronchitis). Four (7%) patients had systemic hypertension, 2 (4%) had insulin-dependent diabetes mellitus, and none had known coronary artery disease. Two (4%) patients were living in a group home at the time of infection. Additional patient characteristics are listed in Table 1.

Of those presenting to medical care, mild symptoms were reported by 43 patients (81%); 9 (17%; 7 adults and 2 children) experienced moderate/severe symptoms. Details of the clinical course of individuals with

Table 1. Patient Characteristics

Variable	Children (N=10)	Adults (N=43)	Total Cohort (N=53)
Male	7 (70%)	24 (56%)	31 (58%)
Age, median, y (IQR)	3 (9)	37 (21)	34 (16)
STAT category of last surgery			
1	4 (40%)	13 (38%)	17 (32%)
2	0 (0)	5 (15%)	5 (9%)
3	2 (20%)	8 (24%)	10 (19%)
4	1 (10%)	8 (24%)	9 (17%)
5	1 (10%)	0 (0)	1 (2%)
Obese	0 (0)	9 (21%)	9 (17%)
Decreased ventricular function (any)	2 (20%)	17 (40%)	19 (36%)
≥Moderate valvular regurgitation (any)	1 (10%)	11 (26%)	12 (23%)
≥Moderate valvular stenosis (any)	0 (0)	2 (5%)	2 (4%)
ACHD Physiological Stage C or D (adult only)	0 (0)	18 (42%)	18 (42%)
Baseline oxygen saturation, mean (SD)	96% (3)	95% (4)	95% (4)
RVSP, median, mm Hg (IQR)	35 (5)	35 (16)	35 (16)
Creatinine, mean (SD)	0.38 (0.15)	0.84 (0.20)	0.78 (0.24)
Hematocrit, mean (SD)	39 (6)	42 (9)	41 (9)
Medications			
Aspirin	2 (20%)	13 (30%)	15 (28%)
Ace-inhibitors (any)	2 (20%)	8 (19%)	10 (19%)
Beta-blockers (any)	1 (10%)	15 (35%)	16 (30%)
Oral anticoagulation	1 (10%)	11 (26%)	12 (23%)
Furosemide	2 (20%)	6 (14%)	8 (15%)
Genetic syndrome	3 (30%)	5 (12%)	8 (15%)
Symptoms			
Fever	4 (40%)	33 (77%)	37 (69%)
Cough	6 (60%)	27 (63%)	33 (62%)
Shortness of breath	1 (10%)	13 (30%)	14 (26%)
Any gastrointestinal symptom (nausea, emesis, diarrhea)	0 (0)	4 (9%)	4 (8%)
Anosmia	0 (0)	12 (28%)	12 (23%)
Ageusia	0 (0)	15 (35%)	15 (28%)
Lethargy	1 (10%)	15 (35%)	16 (30%)
Moderate/severe infection	2 (20%)	7 (16%)	9 (17%)
Deceased	0 (0%)	3 (7%)	3 (6%)

ACHD indicates adult congenital heart disease; IQR, interquartile range; RVSP, right ventricular systolic pressure; and STAT, The Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery.

moderate/severe infections are presented in Table 2. Among those with moderate/severe symptoms, 2 (22%) were maintained at home or long-term care facilities on increased supplemental oxygen, and 7 (77%) were hospitalized. Three (6% of all symptomatic; 33% of moderate/severely symptomatic) patients died. Both patients living in long-term care facilities at the time of infection died. Six of the 7 hospitalized patients with moderate/severe infection had worsening hypoxemia requiring supplemental oxygen and 3 required intubation. One hospitalized patient required inotropic support. Two underwent transthoracic echocardiography during admission, with each study demonstrating no change from baseline. No changes in cardiac medications were required for patients with mild infections or those treated as an outpatient. Among nonhospitalized patients, all were cared for at home or at their long-term care facilities via telemedicine and 5 (10%) were prescribed hydroxychloroquine sulfate (Plaquenil) and azithromycin at the time of diagnosis.

The association between select exposures and the outcome of interest are displayed in Table 3. After Bonferroni correction, moderate/severe infection was associated with concurrent genetic syndrome, and in adult patients, adult congenital heart disease Physiological Stage C and D (Table 2). Notably,

Table 2. Patient Characteristics and Disease Trajectory of Individuals With Moderate/Severe COVID-19 Infection and Congenital Heart Disease

Age/ Sex	Cardiac Dx	Cardiac Status and Additional Comorbidities	Laboratory Values (Peak)	Outcome	Current Disposition
2 yo Female	AVC	Trisomy 21 Duodenal atresia G-tube	ESR: 36 CRP: 14 Trop: WNL	Hospitalized Treated for fever and diarrhea	At baseline (at home)
3 yo Male	AVC Pulmonary hypertension	Trisomy 21, OSA, chronic lung disease, seizure disorder, normal biventricular function PHT dual therapy (ambrisentan and tadalafil)	ESR: 59 CRP: 54 IL-6: WNL Trop: WNL	Hospitalized, inotropic support, supplemental oxygen (face mask)	At baseline (at home)
21 yo Male	AVC Eisenmenger	Trisomy 21, OSA, obesity, normal biventricular function, PHT monotherapy (tadalafil)	Not available	Hospitalized, intubated, tracheostomy performed	Tracheostomy collar with baseline nighttime CPAP (at home)
23 yo Male	TOF/PA	DiGeorge, obesity, moderate RVOT obstruction (estimated RVSP 55 mm Hg), free PI Branch LPA stenosis	ESR: 62 CRP: NA IL-6: 54 Trop: WNL	Hospitalized, supplemental oxygen (nasal cannula), treated for hypocalcemia	At baseline (at home)
23 yo Male	TA/Fontan	obesity, paroxysmal atrial flutter, paced, baseline oxygen saturation 92%	Not available	Supplemental oxygen (nasal cannula)	At baseline (at home)
25 yo Female	AVC Eisenmenger	Trisomy 21, OSA, normal biventricular function, PHT monotherapy (sildenafil)	ESR: WNL CRP: WNL IL-6: NA Trop: WNL	Hospitalized Supplemental oxygen (face mask)	At baseline (at home)
34 yo Male	TOF/PA	Biventricular dysfunction, obesity, prior pneumonia	ESR: 125 CRP: 193 IL-6: 17 Trop: 154	Hospitalized Intubated, died of multiorgan dysfunction	Deceased
65 yo Male	Unrepaired DCRV	Trisomy 21, nonverbal, Severe RVOT obstruction (estimated RVSP 81 mm Hg)	Not available	Hospitalized from care facility Intubated, died of refractory respiratory failure	Deceased
69 yo Female	VSD Eisenmenger	Severe RV dysfunction	Not available	Deceased at care facility (not hospitalized)	Deceased

AVC indicates atrioventricular canal defect; COVID-19, coronavirus disease 2019; CPAP, continuous positive airway pressure; CRP, C-reactive protein; DCRV, double chamber right ventricle; ESR, erythrocyte sedimentation rate; G-tube, gastrostomy tube; LPA, left pulmonary artery; NA, Not available; OSA, obstructive sleep apnea; PA, pulmonary atresia; PHT, Pulmonary hypertension; PI, Pulmonary insufficiency; RVOT, right ventricular outflow tract; RVSP, right ventricular systolic pressure; TA, tricuspid atresia; TOF, tetralogy of Fallot; Trop, high-sensitivity troponin; VSD, ventricular septal defect; WNL, within normal limits; and yo, years old.

obesity, PH, anatomic complexity, single ventricle status, decreased ventricular function, medication type, ≥18 years of age, sex, valvular disease, and STAT score of the last congenital heart surgery were not significantly associated with moderate/severe infection in our cohort. Of those admitted, all 3 deaths occurred in our 3 oldest patients—a 34 year old, a 65 year old, and a 69 year old.

The mean duration of symptoms was 12 days (SD 8 days). Notably, individuals with decreased subsystemic, subpulmonic, or single ventricular function had significantly longer duration of symptoms (18 days versus 9 days, P=0.0004). Figure 1 illustrates a box plot of symptom duration by ventricular function. We found no significant association among symptom duration and >18 years of age, type of congenital heart disease, a history of PH, body mass index, or STAT category of most recent surgery.

DISCUSSION

In our cohort of 53 adult and pediatric patients with CHD, 9 experienced moderate/severe infections and 3 died. History of a genetic syndrome and, for adult patients with CHD, physiological stage C and D were

Table 3. Univariate Association of Select Covariates with Moderate/Severe Infection by Exact Logistic Regression

Variable(s)	OR	*P* Value
Genetic syndrome	35.82	0.0002*
ACHD Physiologic Stage C	19.38	0.0020*
Pulmonary hypertension	15.25	0.011
Obesity	7.34	0.046
Complex congenital anatomy	2.86	0.36
Age (per y)	0.98	0.39
Male sex	1.51	0.87
Single ventricle/Fontan	0.49	0.91
STAT category	1.26	0.61
Decreased ventricular function	1.51	0.81

ACHD indicates adult congenital heart disease; OR, odds ratio; and STAT, The Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery.

*Significant postadjustment for multiple comparisons.

significantly associated with a moderate/severe infection. Additionally, individuals with ventricular dysfunction were more likely to have a longer duration of symptoms. Although our sample size is limited, type of CHD, including single ventricle physiology, was not associated with worse clinical outcomes. These findings may have important implications for risk stratification among individuals with CHD at risk for COVID-19 infection.

While prior studies have identified adult-onset cardiovascular disease as a risk factor for mortality in COVID-19 infections,[13,14] the impact of the virus in patients with CHD remains unknown. At the beginning of the pandemic, many feared that CHD would be as big a risk factor as adult-onset cardiovascular disease. By the end of our study period, the estimated statewide prevalence of COVID-19 infection was 14% (20% in New York City).[15] During the spring of 2020, our institution managed all inpatient COVID-19-positive children and ≈40% of the >10 000 COVID-19 adult admissions at our hospital system. Furthermore, our adult and pediatric congenital heart center follows >7000 patients. Yet only 53 COVID-19 patients with CHD—43 adults and 10 children—presented to medical care for COVID-19. Of these, only 9 children or adults with CHD had moderate/severe symptoms. There were 3 deaths—2 of 7 hospitalized patients and 1 who remained in a facility. This is in line with the 39% mortality experienced across our institution by all COVID-19 admissions during this time period.[16]

That having been said, it is important to note that the median age and the frequency of acquired cardiac risk factors were lower in hospitalized patients in our cohort compared with published reports of hospitalized patients from COVID-19 in New York City at

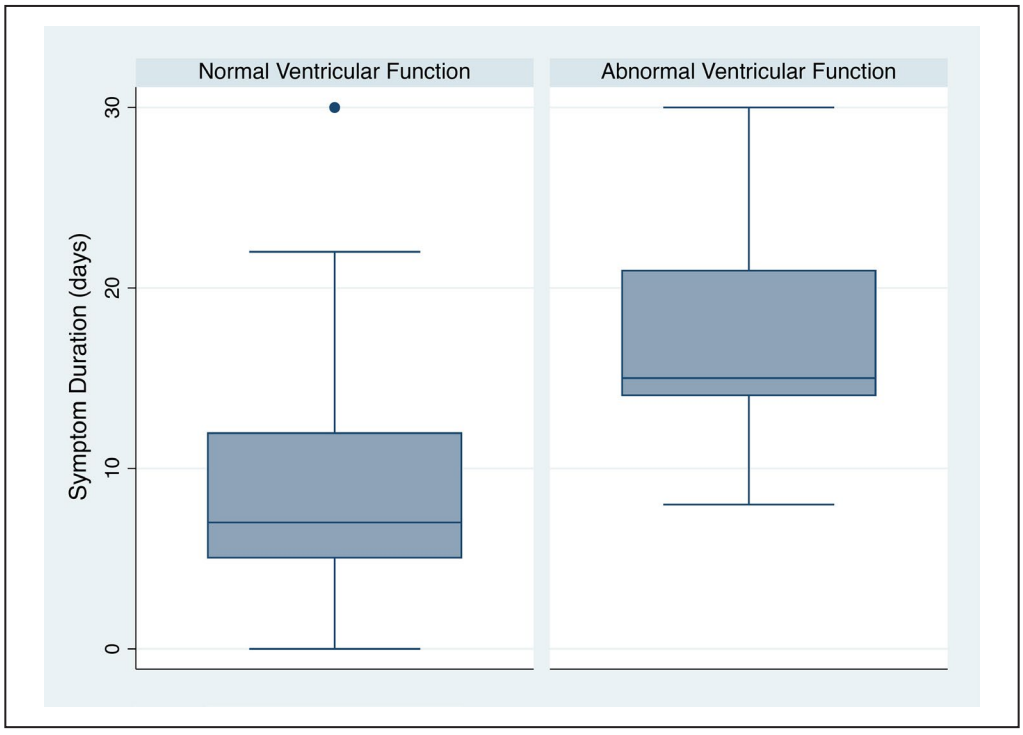

Figure. Duration of COVID-19 symptoms by ventricular function.
The median duration of symptom duration for patients with decreased ventricular function (of any ventricle) was 18 days compared with 9 days for patients with normal ventricular function. COVID-19 indicates coronavirus disease 2019.

large.[17] This may be because the CHD community at large is younger than the general population or because individuals with CHD may have distinct risk factors for severe COVID-19 infection when compared with the general population. It is possible that a cohort of elderly patients with CHD might have a different risk profile than the general population.

The plurality of identified mechanisms by which COVID-19 can cause disease combined with the diversity of anatomic lesions, repairs, and pathophysiology in CHD significantly obfuscate the ability to prognosticate which patients with CHD are at greatest risk for moderate/severe infection. Because the complexity of patients' anatomic lesions and the degree of physiological decompensation are not always correlated, we analyzed their associations with COVID-19 severity separately. We found that congenital lesion or complexity by most recent congenital heart surgery was not associated with patient course. Furthermore, we found no association between individual lesions, including single ventricle physiology, and disease severity. While our sample size is small, these results imply that specific congenital heart lesions may not be sufficient cause alone for severe COVID-19 infection. In contrast, aggregate markers of advanced cardiac disease, such as physiologic stage, may act as a surrogate for overall cardiac fitness across the spectrum of CHD lesions, better defining risk for adverse outcomes from COVID-19 infection in the population with CHD at large.

The presence of a concurrent genetic syndrome was associated with an increased risk of symptom severity, with 5 patients with trisomy 21 and 1 patient with DiGeorge syndrome developing moderate/severe symptoms. There are multiple plausible mechanisms by which genetic syndromes may impact COVID-19 severity. Both trisomy 21 and 22q11 deletion have been associated with alterations in cell-mediated and humoral immunological response.[18,19] Additionally, trisomy 21 has been shown to activate interferon transcriptional response in lymphoblastoid cell lines, circulating monocytes, and T cells, while 22q11 deletions are associated with variable immune defects including decreased T cell function, hypogammaglobulinemia, and poor vaccine-specific antibody response.[20,21] Trisomy 21 and DiGeorge syndrome are also associated with a multitude of additional medical comorbidities including pulmonary abnormalities and renal dysfunction. In aggregate, these risk factors increase risk of morbidity and mortality during viral respiratory infections as demonstrated during the 2009 H1N1 pandemic.[22] Whether additional monogenic causes of CHD[23] confer risk in nonsyndromic patients with CHD remains to be determined.

COVID-19 may potentiate pulmonary vascular disease through multiple mechanisms including pneumonia leading to worsening V/Q mismatch and progressive hypoxic, embolic disease, and hypercapnic vasoconstriction.[24] However, COVID-19 may also directly impact endothelial cells. Multiple studies have demonstrated an accumulation of inflammatory cells within the endothelium in COVID-19 infection, leading to cell death and endothelial cell dysfunction.[25] In patients with clinically significant PH, vascular dysregulation, mediated by endothelial dysfunction, has the potential to lead to progressive vasoconstriction and end-organ damage. These proposed mechanisms notwithstanding, it is still unclear whether the presence of PH alone is a risk factor for the development of severe COVID-19 infection. Despite a significant number of patients with CHD with coincident PH in our patient population, PH was not associated with the outcome in our study. While this may represent underpowering, it is also possible that unidentified host factors play a role in defining the impact of COVID-19 infection in individuals with PH. Future, multicenter studies are necessary to better define risk factors in the PH population.

Limitations

Given inherent limitations to COVID-19 testing availability and accuracy, defining positive cases can be challenging. By including symptomatic individuals with positive household contacts, we may have overestimated the number of symptomatic patients in our cohort with COVID-19. Furthermore, it is known that some patients, particularly children, are minimally symptomatic or asymptomatic. It is, therefore, likely that there were patients with CHD with minimal or no symptoms who were not included in our case count. Furthermore, it is not yet known the extent to which minimally symptomatic or asymptomatic patients might develop long-term sequelae. Our intention, however, was to focus on describing symptomatic patients and to provide estimates of symptomatic patients. Importantly, both strategies for case identification would bias our study towards overestimating symptomatic cases, thus maximizing sensitivity for case identification. Conversely, overly conservative case identification could lead to underestimating symptomatic risk. While it is possible that our patient population exercised stricter adherence to social distancing given early publicized concerns about cardiac risk, these early results appear reassuring. While large-scale antibody testing may allow for more precise estimations of COVID-19 infection in the population with CHD in the future, the relatively low rate of observed symptomatic infection may suggest that the overall risk to patients with CHD without clear physiological risk factors may not differ significantly from the population at large.

Because of our limited sample size and young age of our cohort, we had relatively few patients with acquired cardiovascular disease. As such, the impact of acquired

cardiovascular disease in patients with COVID-19 and CHD remains to be determined. Similarly, it is possible that we were underpowered to accurately determine the risk associated with specific lesions or additional patient characteristics. Large patient registries, currently in development, may help to address this issue. Given the limited number of tests available and reliance on self-reporting, it is likely that mild or asymptomatic cases may have gone unrecognized. However, to our knowledge, this is the largest study to date delineating the impact of COVID-19 infection on patients with CHD followed at a tertiary care congenital heart center.

CONCLUSIONS

Despite evidence that adult-onset cardiovascular disease is a risk factor for worse outcomes among patients with COVID-19, patients with CHD without concomitant genetic syndrome, and adults who are not at advanced physiological stage, do not appear to be disproportionately impacted.

APPENDIX

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