Prevalence of Mental Illness in Adolescents and Adults With Congenital Heart Disease from the Colorado Congenital Heart Defect Surveillance System

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The aim of this study was to estimate the prevalence of the full spectrum of mental illness in adolescents (aged 11 to 17) and adults (aged 18 to 64) with congenital heart defects (CHDs) in the population-level Colorado Congenital Heart Disease Surveillance System. Further we sought to investigate whether severity of the defect, frequency of recent cardiac procedures or underlying genetic disorders influence these estimates. The cohort included patients in clinical care for CHDs between January 1, 2011 and December 31, 2013, identified across multiple healthcare systems and insurance claims. Of 2,192 adolescents with CHDs, 20% were diagnosed with a mental illness with the most prevalent categories being developmental disorders (8%), anxiety disorders (6%), attention, conduct, behavior, impulse control disorders (6%), and mood disorders (5%). Of 6,924 adults with CHDs, 33% were diagnosed with a mental illness with the most prevalent categories being mood disorders (13%), anxiety disorders (13%), and substance-related disorders (6%). Greater lesion complexity was associated with a higher likelihood of anxiety and developmental disorders in both adolescents and adults. Adolescents and adults who had ≥2 cardiac procedures in the 3-year surveillance period had a 3- and 4.5-fold higher likelihood of a mental illness diagnosis, respectively, compared with those who had fewer than 2 cardiac procedures. Finally, patients with a genetic syndrome were more likely to have a mental illness diagnosis. In conclusion, mental illness is a prevalent co-morbidity in the adolescent and adult population with CHDs, thus comprehensive care should include mental health care. **(Am J Cardiol 2019;124:618−626)**

It is estimated that more than 2.4 million people are living with a congenital heart defect (CHD) in the United States, with more adults than children.[1] Continued advances in health care and surgical innovations has led to a growing population of adults with CHDs, with an evolving cadre of co-morbidities,[2] although little is known regarding the burden of mental illness. North American studies that used clinical interview methodology suggest a high burden of mood and anxiety disorders in adults with a CHD,[3−5] correlated with fear of negative clinical evaluation, loneliness and perceived health status. However, these findings are limited to adults who receive care at regional adult congenital heart defect centers.[6] Several genetic disorders present at birth are also associated with both CHDs and mental illness, such as schizophrenia.[7,8] It has long been recognized that executive function impairments are a prominent neurodevelopmental feature in children with CHDs, suggesting a higher risk of attention deficit disorders.[9] Further, children with CHDs are also more likely to have a diagnosis of autism spectrum disorder.[10,11] The prevalence of mental illness beyond mood and anxiety disorders in adolescents and adults with CHDs is currently unknown. The purpose of this study was 3-fold: (1) to estimate the prevalence of the full spectrum of mental illness in a population-based cohort of adolescents and adults with CHDs, (2) to investigate the association between age, defect severity, and mental illness and (3) to determine how presence of genetic syndromes are related to prevalence of mental illness in adolescents and adults with CHDs.

METHODS

The Colorado Congenital Heart Disease Surveillance System (COCHD) aims to identify all adolescents and adults age 11 to 64 years with prevalent CHDs between January 1, 2011 and December 31, 2013. Inclusion criteria included having a qualifying healthcare encounter defined as a CHD lesion listed as an encounter diagnostic code in conjunction with age-eligibility (aged 11 to 64) and residence in the state of Colorado at some point during the 3-year surveillance period. ICD-9-CM diagnosis codes used to determine the qualifying encounter include 745 to 747, 648.5x, and V13.65. ICD-9-CM exclusion codes were 745.5, 746.86, 747.32, 747.5, 747.6x, and 747.8x.

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Case finding was conducted from electronic health records and health insurance claims data from 5 primary case-finding data sources in Colorado. The first was Health Data Compass (Compass), a health data warehouse that includes encounter, procedure, and diagnostic data from each of the ambulatory and inpatient facilities associated with Children's Hospital Colorado and the University of Colorado Hospital (UCHealth). The University of Colorado houses the only comprehensive adult CHD center in the state. The second case-finding data source was Denver Health and Hospital Authority, Colorado's primary safety-net institution that provides care for the majority of low-income patients in the Denver metro area. The third data source was Kaiser Permanente Colorado and the fourth was Centura Health, both large, nonprofit healthcare systems that provide inpatient, emergency, outpatient, and urgent care throughout the state. The final data source was the Center for Improving Value in Health Care, a state legislated, all payer claims database containing 100% of Medicaid claims and claims from 8 commercial health insurance plans in Colorado during the study period.

Once patients with a CHD were identified using the inclusion and exclusion criteria specified above, each case-finding data source was queried to obtain all healthcare encounters that occurred for each CHD case (regardless of the encounter diagnostic code) to ensure that all mental health encounters for each patient throughout the study period were captured. A probabilistic record linkage algorithm was used to reconcile identity of patients within and across the different data sources. The study was approved by the Colorado Multiple Institutional Review Board (Protocol# 18-1082) and a waiver of consent and HIPAA authorization to conduct public health surveillance was granted.

Patients were classified as having mental illness if they had a healthcare encounter between January 1, 2011 and December 31, 2013 with an ICD-9-CM diagnostic code that fell within Clinical Classification Software (CCS) categories 650 to 670,[12] regardless of provider type or principal diagnostic code for the encounter. For the current analysis, several CCS categories were combined or collapsed. The categories for alcohol-related disorders (CCS 660) and substance-related disorders (CCS 661) were collapsed into "substance-related disorders." The category for attention, conduct, and disruptive behavioral disorder (CCS 652) was combined with impulse control disorders (CCS 656) into "attention, conduct, behavior, and impulse control disorders." The category for personality disorders (CCS 658) was combined with miscellaneous disorders (CCS 670) and called "miscellaneous." The category for screening and history of mental health (CCS 663) was excluded from this analysis.

Patients were classified as having a severe CHD if they had common truncus, transposition of the great arteries, congenitally corrected transposition, double outlet right ventricle, tetralogy of Fallot, single ventricle, endocardial cushion defect, pulmonary valve atresia, tricuspid atresia, hypoplastic left heart syndrome, interrupted aortic arch, or total anomalous pulmonary venous return. They were classified as having moderate defects if they had a diagnosis of Ebstein anomaly, subaortic stenosis, coarctation, aortic stenosis, pulmonary artery anomaly, or primum ASD. The remaining patients were classified as having simple lesions. If patients had more than one type of simple lesion diagnosis (e.g., a ventricular septal defect and pulmonary stenosis), they were classified into the moderate severity category.

Procedure codes from each encounter in the 3-year surveillance window were obtained on every patient with a CHD identified. Cardiac procedures, which included any diagnostic, interventional, or surgical procedure to the heart or great vessels, were abstracted from the entire list of procedure codes (see Supplemental Material for a complete list of cardiac procedures). Cardiac procedures were then dichotomized as ≥ 2 or <2. Patients with a CHD were classified as having a genetic syndrome if any of the following ICD-9-CM diagnosis codes were reported during the surveillance period: 758.0 Down syndrome, 758.6 gonadal dysgenesis (includes Turner syndrome), 758.32 22q11.2 deletion syndrome, 758.xx other chromosomal anomalies, and 759.8x other specified congenital anomalies (includes Prader-Willi syndrome, Marfan syndrome, Fragile X syndrome, and other specified congenital anomalies). For analyses genetic syndromes were dichotomized as yes or no.

Prevalence of mental illness was calculated as the proportion of adolescents (age 11 to 17) and adults (age 18 to 64) with a CHD who had a mental illness diagnostic code reported during the 3-year surveillance period, out of the total COCHD surveillance population in the respective age categories. Prevalence was expressed as a percent with 95% confidence intervals calculated assuming a Poisson distribution. Population characteristics were compared according to the presence of a mental illness diagnostic code (yes/no) and further stratified by age, using a Student's *t* test for continuous variables and a chi-square test for categorical variables. Continuous variables were evaluated for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Continuous variables found to be positively skewed were tested using the Wilcoxon rank-sum test. The prevalence of the 2 most common mental illnesses (anxiety and mood disorders) was evaluated across the surveillance age range of 11 to 64 years, with a trendline corresponding to the highest R^2 value identified from testing various linear and polynomial combinations. Separate logistic regression models were used to calculate odds ratios and 95% confidence intervals corresponding to the likelihood of a mental illness diagnosis in adolescents and adults with severe or moderate CHDs (compared with simple lesions), by the number of cardiac procedures during the surveillance period (≥ 2 vs <2) and presence of a genetic syndrome (yes/no). All statistical analyses were performed using SAS software, version 9.4 (SAS Institute Inc., Cary, North Carolina) and alpha < 0.05 was the criteria for statistical significance.

RESULTS

We identified 9,116 unique patients with a CHD between January 1, 2011 and December 31, 2013 in Colorado, in which 2,192 were adolescents (age 11 to 17) and 6,924 were adults (age 18 to 64). The prevalence of a mental illness diagnosis was higher in adults versus adolescents (33% vs 20%, respectively; $p < 0.0001$), Table 1. In adolescents with a CHD, the most prevalent categories of mental illness were developmental disorders; attention, conduct, behavior, and impulse control disorders; and anxiety disorders. In adults

Table 1
Prevalence of mental illness subtypes in adolescents and adults with congenital heart disease in the Colorado Congenital Heart Disease Surveillance System (COCHD)

Variable	Age (years)		p Value*
	11-17 (n = 2,192) % (95% CI)	18-64 (n = 6,924) % (95% CI)	
Any encounter for mental illness†	19.8 (18.1-21.4)	33.4 (32.3-34.5)	<0.0001
Adjustment (n = 154; n = 33 adolescents/n = 121 adults)	1.5 (1.0-2.1)	1.8 (1.4-2.1)	0.43
Anxiety (n = 1,007; n = 131 adolescents/n = 876 adults)	6.0 (4.9-7.0)	12.7 (11.9-13.4)	<0.0001
Delirium, dementia (n = 96; n = 18 adolescents/n = 78 adults)	0.8 (0.4-1.2)	1.1 (0.9-1.4)	0.19
Developmental (n = 344; n = 165 adolescents/n = 179 adults)	7.5 (6.4-8.6)	2.6 (2.2-3.0)	<0.0001
Usually in childhood (n = 89; n = 52 adolescents/n = 37 adults)	2.4 (1.7-3.0)	0.5 (0.4-0.7)	<0.0001
Attention, conduct, behavior, and impulse control disorders (n = 222; n = 131 adolescents/n = 91 adults)	6.0 (5.0-7.0)	1.3 (1.1-1.6)	<0.0001
Mood (n = 1,034; n = 115 adolescents/n = 919 adults)	5.2 (4.3-6.2)	13.3 (12.5-14.1)	<0.0001
Schizophrenia (n = 119; n = 9 adolescents/n = 110 adults)	0.4 (0.1-0.7)	1.6 (1.3-1.9)	<0.0001
Substance-related (n = 451; n = 25 adolescents/n = 426 adults)	1.1 (0.7-1.6)	6.2 (5.6-6.7)	<0.0001
Suicide and self-inflicted injury (n = 35; n = 6 adolescents/n = 29 adults)	0.3 (0.1-0.5)	0.4 (0.3-0.6)	0.29
Miscellaneous (n = 319; n = 49 adolescents/n = 270 adults)	2.2 (95% CI 1.6-2.9)	3.9 (95% CI 3.4-4.4)	<0.0001

Classification of mental illness was based on the Clinical Classification Software (CCS) groupings. Adjustment disorders correspond to CCS category 650, anxiety disorders to CCS category 651, delirium and dementia to CCS category 653, developmental disorders to CCS category 654, disorders usually diagnosed in childhood to CCS category 655, attention, conduct, behavior, and impulse control disorders is comprised of CCS categories 652 (attention-deficit/conduct/disruptive behavior) and 656 (impulse control disorders), mood disorders is CCS category 657, schizophrenia and other psychotic disorders is CCS category 659, substance-related disorders is comprised of CCS categories 660 (alcohol-related disorders) and 661 (substance-related disorders), suicide and intentional self-inflicted injury is CCS category 662, and miscellaneous disorders is comprised of CCS categories 658 (personality disorders) and 670 (miscellaneous mental health disorders).

* p Value for difference in prevalence of mental illness subtypes between adolescents and adults.

† Any healthcare encounter with a mental illness diagnosis during the 3-year surveillance period.

with a CHD, the most prevalent categories of mental illness were mood, anxiety, and substance-related disorders.

Figure 1 shows the relation between age and prevalence of the 2 most common mental health diagnoses in the CHD population; mood and anxiety disorders. The prevalence of mood disorders increased from adolescence through the 3rd decade of life, plateauing in the 4th decade of life. Similarly, the prevalence of anxiety disorders increased from adolescence to young adulthood, peaking in the 3rd and 4th decade of life, then decreasing in late adulthood.

Table 2 presents demographic, clinical, and healthcare utilization characteristics of adolescents and adults with CHDs, stratified by presence of mental illness diagnosis during the 3-year surveillance period. Demographic differences in adolescents with a CHD were not evident according to mental illness status. Adolescent CHD cases with a mental illness diagnosis were less likely to have a simple lesion (more likely to have a moderate or complex lesion) and were more likely to have a genetic disorder, greater number of inpatient hospitalizations and cardiac procedures performed during the 3-year period than those without a mental health diagnosis. In adults with a CHD, those with mental illness diagnosis were more likely to be older, have government health insurance and to be non-Hispanic white than adults without a mental illness diagnosis. Adult CHD cases with a mental illness diagnosis were more likely to have a cardiology clinic visit, a greater number of inpatient hospitalizations and cardiac procedures performed during the 3-year surveillance period than those without a mental illness diagnosis.

The association between CHD severity and prevalence of mental illness is shown in Figure 2, stratified by adolescents and adults. The corresponding odds ratios and 95% confidence intervals are presented in Table 3. When examining specific mental health diagnoses in adolescents, those with moderate or severe CHD lesions were more likely to have anxiety, developmental disorders, and disorders usually occurring in childhood compared with those with simple lesions. Adolescents with a severe defect were more likely to have a delirium or dementia disorder, schizophrenia, or a miscellaneous mental illness diagnosis compared with adolescents with a simple defect. When examining specific mental health diagnoses in adults, those with moderate or severe CHDs were more likely than those with simple lesions to have an adjustment disorder, anxiety disorder, developmental disorder, disorders usually occurring in childhood, attention, conduct, behavior and impulse control disorder, or a mood disorder.

Figure 3 shows the association between having ≥2 cardiac procedures performed during the 3-year surveillance period and likelihood of a mental illness diagnosis code for adolescents and adults with a CHD. The corresponding odds ratios and 95% confidence intervals are presented in Table 4. In both adolescents and adults with a CHD, patients with ≥2 cardiac procedures were more likely to have a mental illness diagnostic code reported compared to those with <2 cardiac procedures. When examining specific mental health diagnoses in adolescents, those with ≥2 cardiac procedures were more likely to have an adjustment disorder, anxiety disorder, delirium or dementia disorders, attention, conduct, behavior and impulse control disorders, a mood disorder, substance-related disorder, or a miscellaneous mental illness diagnosis compared to adolescents with <2 cardiac procedures. When examining specific diagnoses in adults, those with ≥2 cardiac procedures were

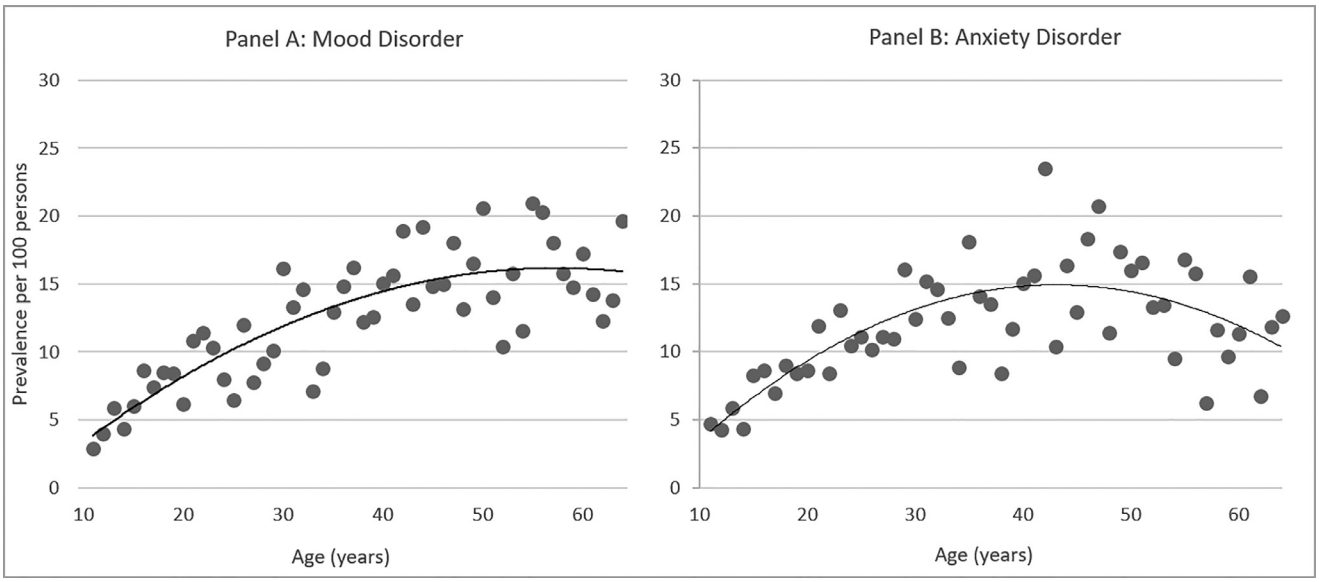

Figure 1. Prevalence of mood and anxiety disorders in patients with congenital heart disease across the age range of 11 to 64 years in the Colorado Congenital Heart Disease Surveillance System (COCHD). Classification of mood and anxiety disorders was based on the Clinical Classification Software (CCS) groupings. Anxiety disorders correspond to CCS category 651 and mood disorders correspond to CCS category 657. Prevalence of mood and anxiety disorders calculated at each age, represented by the dots in the graph, and the best-fit trendline was modeled. For mood disorder panel A: equation $-0.001x^2 + 0.66x - 2.68$; $R^2 = 0.68$. For anxiety disorder panel B: equation $-0.01x^2 + 0.90x - 4.53$; $R^2 = 0.51$.

Table 2
Demographic and clinical characteristics of adolescents and adults with congenital heart disease according to prevalent mental illness in the Colorado Congenital Heart Disease Surveillance System

Variable	Age (years)					
	11-17 (n = 2,192)			18-64 (n = 6,924)		
	Mental illness diagnosis^ (n = 433)	No mental illness diagnosis (n = 1,759)	p Value*	Mental illness diagnosis^ (n = 2,312)	No mental illness diagnosis (n = 4,612)	p Value*
Demographic characteristics						
Age (years)	14 ± 2	14 ± 2	0.14	42 ± 14	39 ± 14	<0.0001
Female gender	192 (44%)	737 (42%)	0.37	1,193 (52%)	2,491 (54%)	0.05
Insurance status			0.13			<0.0001
Private	196 (45%)	858 (49%)		1,154 (50%)	2,794 (61%)	
Government	220 (51%)	830 (47%)		996 (43%)	1,623 (35%)	
Self-pay	9 (2%)	53 (3%)		93 (4%)	147 (3%)	
Other	7 (2%)	18 (1%)		69 (3%)	48 (1%)	
Race/ethnicity			0.40			<0.0001
Non-Hispanic white	172 (40%)	648 (37%)		1,222 (53%)	1,791 (39%)	
Non-Hispanic black	19 (4%)	51 (3%)		94 (4%)	95 (2%)	
Any Hispanic	104 (24%)	442 (25%)		289 (13%)	524 (11%)	
Non-Hispanic Other race	29 (7%)	99 (6%)		98 (4%)	215 (5%)	
Missing	109 (25%)	519 (29%)		609 (26%)	1,987 (43%)	
Clinical characteristics						
Defect severity			<0.0001			<0.0001
Simple lesion complexity	117 (27%)	696 (40%)		1,139 (49%)	2,673 (58%)	
Moderate lesion complexity	197 (45%)	715 (41%)		903 (39%)	1,308 (28%)	
Severe lesion complexity	119 (28%)	348 (19%)		270 (12%)	631 (14%)	
Cardiology clinic visit in 3-year period	207 (48%)	830 (47%)	0.82	1,179 (51%)	2,161 (46%)	0.001
†Number of inpatient admissions	4 (2-10)	2 (1-5)	0.03	6 (2-14)	3 (2-7)	<0.0001
†Number of cardiac procedures	2 (1-3)	2 (1-2)	0.06	2 (1-4)	1 (1-2)	0.01
Genetic syndromes	110 (25%)	131 (8%)	<0.0001	122 (5%)	210 (5%)	0.18

Continuous data presented as mean ± SD and comparisons made using the unpaired Students *t* test. Categorical data are presented as number (%) and comparisons were made using a chi-square test.

^ Any healthcare encounter with a mental illness diagnosis during the 3-year surveillance period.

* p Value for difference in prevalence of mental illness diagnosis across categories of patient characteristics.

† Data are presented as median (IQR), comparisons made using the Wilcoxon rank-sum test.

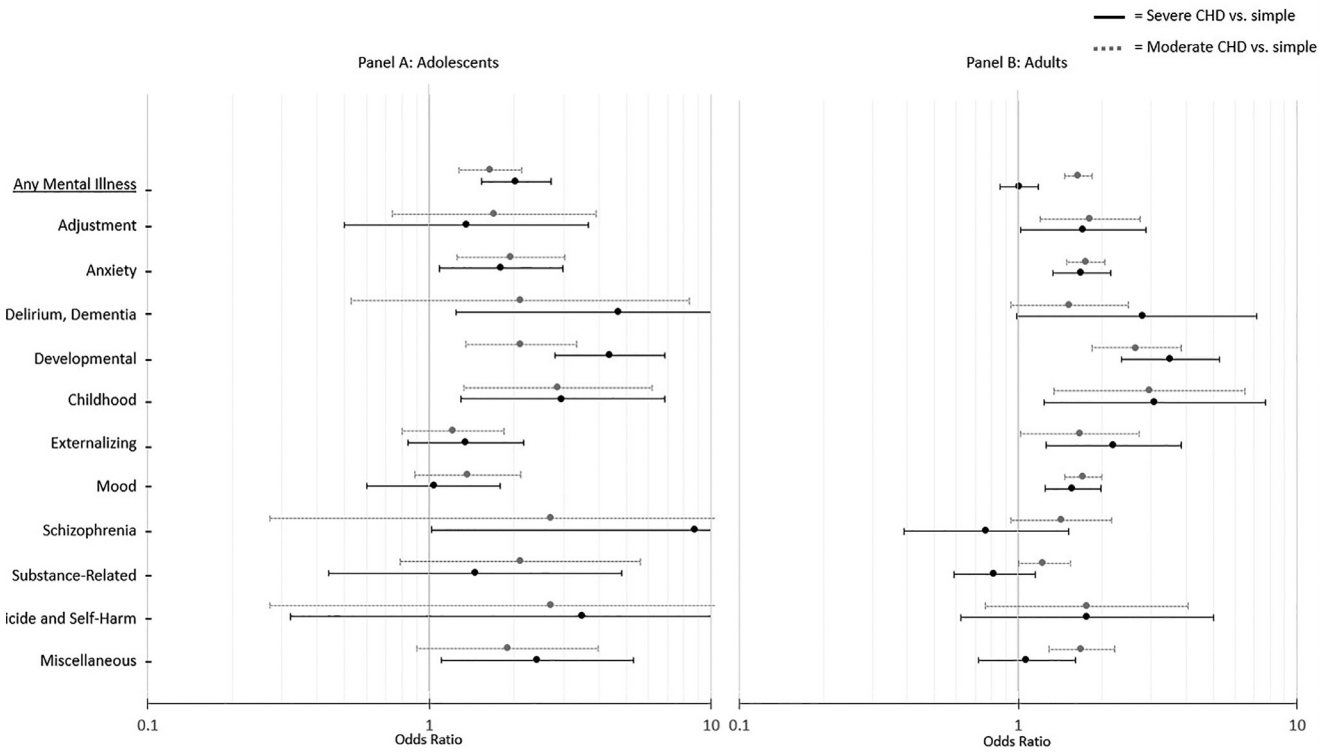

Figure 2. The association between prevalent mental illness and severity of congenital heart defect in the Colorado Congenital Heart Disease Surveillance System (COCHD). Panel A: Adolescents aged 11 to 17 years. Panel B: Adults aged 18 to 64 years. Odds ratio (OR) and 95% confidence interval expressed for the odds of a mental illness diagnosis in the 3-year surveillance window for patients with severe or moderate CHD compared to those with a simple CHD lesion. * Severe congenital heart defects included common truncus, transposition of the great arteries, congenitally corrected transposition, double outlet right ventricle, tetralogy of Fallot, single ventricle, endocardial cushion defect, pulmonary valve atresia, tricuspid atresia, hypoplastic left heart syndrome, interrupted aortic arch, or total anomalous pulmonary venous return. Moderate disease included Ebstein anomaly, subaortic stenosis, coarctation, aortic stenosis, pulmonary artery anomaly, or primum atrial septal defect. The remaining patients were classified as having simple lesions. Patients with >1 type of simple lesion diagnoses (e.g., a ventricular septal defect and pulmonary stenosis) were classified into the moderate disease category.

more likely than those with <2 cardiac procedures to have an adjustment disorder, anxiety disorder, delirium or dementia disorder, attention, conduct, behavior and impulse control disorder, a mood disorder, schizophrenia, substance-related disorder, or a miscellaneous mental illness diagnosis.

Patients with a CHD and a genetic disorder were 63% more likely to have a mental illness diagnosis in our 3-year study period compared to patients with a CHD who did not have a genetic syndrome (Table 5). Patients with a CHD and a genetic syndrome were over 2-fold more likely to have a delirium or dementia disorder, over 15-fold more likely to have a developmental disorder and over 3.5-fold more likely to be diagnosed with an attention, conduct, behavior, and impulse control disorder, compared to patients with a CHD and no genetic syndrome. We also found a 77% reduction in substance-related disorders for patients with a CHD and a genetic syndrome compared with those who did not have a genetic syndrome.

DISCUSSION

The growing population of adolescents and adults with a CHD has evolving health care needs, including mental health care. In a statewide cohort of adolescents and adults with CHDs, the prevalence of any mental health diagnosis code reported in a 3-year surveillance period was 33% in adults and 20% in adolescents. In both adolescents and adults, the prevalence of an anxiety disorder was 70% to 90% higher for patients with moderate or severe lesions compared to those with simple lesions. We found that anxiety and mood disorders were >3 times more likely in both adolescents and adults with a CHD who had a ≥2 cardiac procedures during our 3-year surveillance period, suggesting providers involved in the care of patients with a CHD should develop mechanisms to screen for mental illness and make appropriate referrals to mental health specialists for this population.

The most common mental illness diagnosis in adolescents with a CHD was developmental disorders, affecting 8% of adolescents in the COCHD cohort. Previous work in young children has identified developmental delays in ≥1 area (cognitive, language, and/or motor skills) at ≥1 assessment in up to 75% of at-risk patients with CHDs,[13] manifesting as persistent developmental delays and neuropsychological deficits.[14] Brain imaging in children and adolescents with a CHD demonstrate both diffuse abnormalities as well as focal or multifocal abnormalities suggestive of thromboembolic events as well as hypoperfusion injuries.[15,16] Although developmental disorders demonstrated lower prevalence in the adult population compared with adolescents, other work has stressed the

Table 3
The association between prevalent mental illness and severity of congenital heart defect in the Colorado Congenital Heart Disease Surveillance System (COCHD)

Variable	Age (years)									
	11-17					18-64				
	Simple lesion complexity (n = 813)	Moderate lesion complexity (n = 912)		Severe lesion complexity (n = 467)		Simple lesion complexity (n = 3,812)	Moderate lesion complexity (n = 2,211)		Severe lesion complexity (n = 901)	
		OR (95% CI)	p Value	OR (95% CI)	p Value		OR (95% CI)	p Value	OR (95% CI)	p Value
Any encounter for mental illness	Ref	1.6 (1.3-2.1)	0.01	2.0 (1.5-2.7)	0.0002	Ref	1.6 (1.5-1.8)	<0.0001	1.0 (0.9-1.2)	0.32
Adjustment (n = 154; n = 33 adolescents/ n = 121 adults)	Ref	1.7 (0.8-3.8)	0.29	1.4 (0.5-3.7)	0.82	Ref	1.8 (1.2-2.6)	0.01	1.7 (1.0-2.9)	0.03
Anxiety (n = 1,007; n = 131 adolescents/ n = 876 adults)	Ref	1.9 (1.3-3.0)	0.02	1.8 (1.1-3.0)	0.04	Ref	1.7 (1.5-2.0)	<0.0001	1.7 (1.3-2.2)	0.02
Delirium, dementia (n = 96; n = 18 adolescents/n = 78 adults)	Ref	2.1 (0.5-8.1)	0.94	4.7 (1.2-17.8)	0.02	Ref	1.5 (1.0-2.4)	0.14	2.8 (1.0-7.2)	0.08
Developmental (n = 344; n = 165 adolescents/n = 179 adults)	Ref	2.1 (1.4-3.3)	0.03	4.4 (2.8-6.8)	<0.0001	Ref	2.6 (1.8-3.6)	0.04	3.5 (2.3-5.3)	<0.0001
Usually in childhood (n = 89; n = 52 adolescents/n = 37 adults)	Ref	2.8 (1.3-6.0)	0.01	3.0 (1.3-6.8)	0.01	Ref	2.8 (1.3-6.0)	0.03	3.1 (1.2-7.7)	0.01
Attention, conduct, behavior, and impulse control disorders (n = 222; n = 131 adolescents/n = 91 adults)	Ref	1.2 (0.8-1.8)	0.77	1.4 (0.8-2.2)	0.34	Ref	1.6 (1.0-2.6)	0.04	2.2 (1.3-3.8)	0.04
Mood (n = 1,034; n = 115 adolescents/ n = 919 adults)	Ref	1.4 (0.9-2.1)	0.13	1.0 (0.6-1.8)	0.62	Ref	1.7 (1.5-2.0)	<0.0001	1.6 (1.3-2.0)	0.03
Schizophrenia (n = 119; n = 9 adolescents/ n = 110 adults)	Ref	2.7 (0.3-25.8)	0.90	8.8 (1.0-75.5)	0.02	Ref	1.4 (1.0-2.1)	0.35	0.8 (0.4-1.5)	0.19
Substance-related (n = 451; n = 25 adolescents /n = 426 adults)	Ref	2.1 (0.8-5.5)	0.17	1.5 (0.4-4.8)	0.99	Ref	1.2 (1.0-1.5)	0.01	0.8 (0.6-1.2)	0.08
Suicide and self-inflicted injury (n = 35; n = 6 adolescents/n = 29 adults)	Ref	2.7 (0.3-25.8)	0.67	3.5 (0.3-38.6)	0.41	Ref	1.7 (0.8-3.9)	0.51	1.8 (0.6-5.0)	0.55
Miscellaneous (n = 319; n = 49 adolescents/ n = 270 adults)	Ref	1.9 (0.9-3.9)	0.51	2.4 (1.1-5.3)	0.03	Ref	1.7 (1.3-2.2)	0.001	1.1 (0.7-1.6)	0.34

*Odds ratio (OR) and 95% confidence interval expressed for the odds of a mental illness diagnosis in the 3-year surveillance window for patients with severe or moderate CHD compared to those with a simple CHD lesion, stratified by adolescents (aged 11 to 17 years) and adults (aged 18 to 64 years).

*Severe congenital heart defects included common truncus, transposition of the great arteries, congenitally corrected transposition, double outlet right ventricle, tetralogy of Fallot, single ventricle, endocardial cushion defect, pulmonary valve atresia, tricuspid atresia, hypoplastic left heart syndrome, interrupted aortic arch or total anomalous pulmonary venous return. Moderate disease included Ebstein anomaly, subaortic stenosis, coarctation, aortic stenosis, pulmonary artery anomaly, or primum atrial septal defect. The remaining patients were classified as having simple lesions. Patients with >1 type of simple lesion diagnoses (for example a ventricular septal defect and pulmonary stenosis) were classified into the moderate disease category.

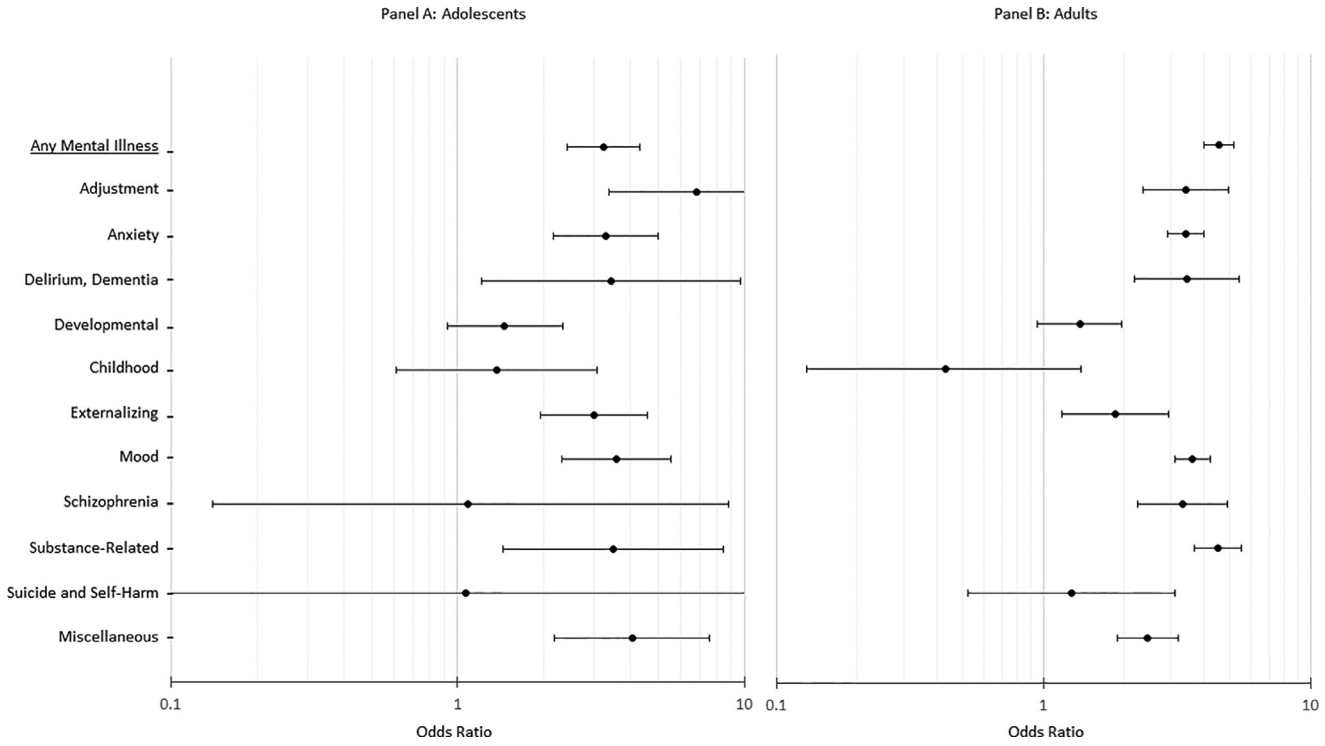

Figure 3. The association between prevalent of mental illness and number of cardiac procedures in adolescents and adults in the Colorado Congenital Heart Disease Surveillance System (COCHD). Panel A: Adolescents aged 11 to 17 years. Panel B: Adults aged 18 to 64 years. Odds ratio (OR) and 95% confidence interval expressed for the odds of a mental illness diagnosis for patients with ≥2 cardiac procedures compared to those with <2 cardiac procedures in the 3-year surveillance window.

Table 4
The association between prevalent of mental illness and number of cardiac procedures in adolescents and adults in the Colorado Congenital Heart Disease Surveillance System (COCHD)

Variable	Age (years)					
	11-17			18-64		
	<2 cardiac procedures (n = 1967) OR (95% CI)	≥2 cardiac procedures (n = 225) OR (95% CI)	p Value	<2 cardiac procedures (n = 5742) OR (95% CI)	≥2 cardiac procedures (n = 1182) OR (95% CI)	p Value
Any encounter for mental illness	Ref	3.2 (2.4-4.3)	<0.0001	Ref	4.5 (4.0-5.2)	<0.0001
Adjustment (n = 154; n = 33 adolescents/n = 121 adults)	Ref	6.8 (3.4-13.8)	<0.0001	Ref	3.4 (2.4-4.9)	<0.0001
Anxiety (n = 1,007; n = 131 adolescents/n = 876 adults)	Ref	3.3 (2.2-5.0)	<0.0001	Ref	3.4 (2.9-4.0)	<0.0001
Delirium, dementia (n = 96; n = 18 adolescents/n = 78 adults)	Ref	3.4 (1.2-9.7)	0.02	Ref	3.5 (2.2-5.4)	<0.0001
Developmental (n = 344; n = 165 adolescents/n = 179 adults)	Ref	1.5 (0.9-2.3)	0.11	Ref	1.4 (1.0-2.0)	0.09
Usually in childhood (n = 89; n = 52 adolescents/n = 37 adults)	Ref	1.4 (0.6-3.1)	0.44	Ref	0.4 (0.1-1.4)	0.16
Attention, conduct, behavior, and impulse control disorders (n = 222; n = 131 adolescents/n = 91 adults)	Ref	3.0 (1.9-4.6)	<0.0001	Ref	1.9 (1.2-3.0)	0.01
Mood (n = 1,034; n = 115 adolescents/n = 919 adults)	Ref	3.6 (2.3-5.6)	<0.0001	Ref	3.6 (3.1-4.2)	<0.0001
Schizophrenia (n = 119; n = 9 adolescents/n = 110 adults)	Ref	1.1 (0.1-8.8)	0.93	Ref	3.3 (2.3-4.9)	<0.0001
Substance-related (n = 451; n = 25 adolescents /n = 426 adults)	Ref	3.5 (1.4-8.4)	0.01	Ref	4.5 (3.7-5.5)	<0.0001
Suicide and self-inflicted injury (n = 35; n = 6 adolescents/ n = 29 adults)	Ref	1.1 (0.1-20.7)	0.97	Ref	1.3 (0.5-3.1)	0.60
Miscellaneous (n = 319; n = 49 adolescents/n = 270 adults)	Ref	4.1 (2.2-7.6)	<0.0001	Ref	2.5 (1.9-3.2)	<0.0001

* Odds ratio (OR) and 95% confidence interval expressed for the odds of a mental illness diagnosis for patients with ≥2 cardiac procedures compared to those with <2 cardiac procedures in the 3-year surveillance window, stratified by adolescents (aged 11 to 17) versus adults.

Table 5
The association between prevalence of mental illness and the presence of a genetic disorder and in adolescents and adults with congenital heart disease in the Colorado Congenital Heart Disease Surveillance System (COCHD)

Variable	Presence of a genetic syndrome (yes/no)		p Value
	No (n = 8,543) OR (95% CI)	Yes (n = 573) OR (95% CI)	
Any encounter for mental illness	Ref	1.6 (1.4-1.9)	<0.0001
Adjustment (n = 154; n = 33 adolescents/n = 121 adults)	Ref	0.8 (0.4-1.7)	0.57
Anxiety (n = 1,007; n = 131 adolescents/n = 876 adults)	Ref	1.2 (0.9-1.5)	0.29
Delirium, dementia (n = 96; n = 18 adolescents/n = 78 adults)	Ref	2.2 (1.2-4.0)	0.01
Developmental (n = 344; n = 165 adolescents/n = 179 adults)	Ref	15.3 (12.1-19.3)	<0.0001
Usually in childhood (n = 89; n = 52 adolescents/n = 37 adults)	Ref	6.8 (4.3-10.7)	<0.0001
Attention, conduct, behavior, and impulse control disorders (n = 222; n = 131 adolescents/n = 91 adults)	Ref	3.6 (2.5-5.1)	<0.0001
Mood (n = 1,034; n = 115 adolescents/n = 919 adults)	Ref	0.8 (0.6-1.0)	0.06
Schizophrenia (n = 119; n = 9 adolescents/n = 110 adults)	Ref	0.8 (0.4-1.8)	0.58
Substance-related (n = 451; n = 25 adolescents /n = 426 adults)	Ref	0.2 (0.1-0.5)	0.0001
Suicide and self-inflicted injury (n = 35; n = 6 adolescents/n = 29 adults)	Ref	0.4 (0.1-3.2)	0.42
Miscellaneous (n = 319; n = 49 adolescents/n = 270 adults)	Ref	1.6 (1.1-2.4)	0.01

*Odds ratios (OR) and 95% confidence intervals (CI) calculated as the likelihood of a mental illness diagnosis for patients with a genetic disorder compared to those without.

*Patients with a CHD were classified as having a genetic syndrome if any of the following ICD-9-CM diagnosis codes were reported during the surveillance period: 758.0 Down syndrome, 758.6 gonadal dysgenesis (includes Turner syndrome), 758.32 22q11.2 deletion syndrome, 758.xx other chromosomal anomalies, 759.8x other specified congenital anomalies (includes Prader-Willi syndrome, Marfan syndrome, Fragile X syndrome, and other specified congenital anomalies).

importance of possible neurocognitive decline as patients with a CHD age.[17] Adults with a CHD are at increased risk of both heart failure and atrial arrhythmias, both of which are associated with worse executive function, cognitive impairment, and dementia.[18–20] Neurocognitive outcomes have not been well studied in adults with CHDs, thus additional research is needed to understand the clinical implications.

Attention, conduct, behavior, and impulse control disorders were also common in adolescents with CHDs at a prevalence of 6.0%, and lower in adults with a CHD at 1.3%. However alcohol and substance-related disorders were diagnosed in 6.2% of adults with CHDs. Other studies suggest a link between externalizing disorders, including attention, conduct, behavior, and impulse control disorders, in children and early onset alcohol missuse.[21,22] Therefore, it is important to develop methods to improve screening and management practices for attention, conduct, behavior, and impulse control disorders, likely in combination screening for substance abuse disorders, in patients with a CHD.

Findings from the present study are consistent with higher prevalence of mental illness in patients with an identified genetic syndrome. In cohort studies, patients with 22q11.2 deletion syndrome have higher prevalence of attention, conduct, behavior, and impulse control disorders, schizophrenia, and autism spectrum disorders.[8] Patients with Down syndrome have a higher prevalence of psychosis, autism, and depression with psychotic features compared with non-Down syndrome patients with a similar degree of intellectual disabilities.[23] Thus, underlying genetic susceptibility is an important contributor to mental illness in patients with CHDs.

There are limitations and important strengths to consider in the interpretation of our study findings. Identification of patients with a CHD and mental illness was obtained from diagnostic codes, thus there is risk of misclassification of both CHD and mental illness status. The COCHD surveillance system was restricted to participating organizations in Colorado which included a diverse network of healthcare systems and a state-level all payer claims database; however, patients who received mental health care outside of our network were not captured and thus not included in this study. Incomplete case ascertainment would likely underestimate the true burden of mental illness in this cohort. Patients with a CHD may choose an independent mental health provider for a variety of reasons, including limited access barriers or preference for privacy owing to the ongoing stigma associated with mental illness. This study was limited to patients who received a mental illness code between 2011 and 2013, thus diagnoses that occurred before or after our surveillance system would not be captured. Finally, a comparison population of patients without CHDs was not available, thus we were unable to evaluate if mental health diagnoses are more prevalent in patients with a CHD relative to the general population. Strengths of our study include the use of a population-based surveillance system in the United States that included a high proportion of patients with government insurance (40%). Additionally, a probability-based record linkage algorithm was used to de-duplicate patients within and across healthcare systems, reducing the risk of overestimating prevalence in this population. Finally, this is one of the largest studies in the United States to assess the occurrence of mental illness in adolescents and adults with a CHD.

In conclusion, understanding the link between congenital heart disease and mental illness is crucial in providing comprehensive, patient-centered cardiac and mental health care.

Disclosures

The authors have no conflicts of interest to disclose.

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Supplementary materials

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