

ADULT CONGENITAL HEART DISEASE

Relevant Guidelines

ACC/AHA 2025 guideline on Adult Congenital Heart Disease

2025 ACC/AHA/HRS/ISACHD/SCAI Guideline for the Management of Adults With Congenital Heart Disease.
JACC 2025

ESC 2020 guidelines on Adult Congenital Heart Disease

2020 ESC Guidelines for the management of adult congenital heart disease. *Eur Heart J*. 2020.

ESC 2021 guidelines on heart failure

2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J*

ESC 2021 guidelines on pacing and cardiac resynchronization

2021 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy. *Eur Heart J*. 2021.

ESC 2022 Guidelines on ventricular arrhythmias and prevention of sudden cardiac death

2022 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death. *Eur Heart J*. 2022.

ESC 2022 Guidelines on noncardiac surgery

2022 ESC Guidelines on cardiovascular assessment and management of patients undergoing non-cardiac surgery.
Eur Heart J. 2022

ESC 2024 guidelines on peripheral and aortic diseases

2024 ESC Guidelines for the management of peripheral arterial and aortic diseases. *Eur Heart J*. 2024.

2020 ESC Guidelines on sports

2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease. *Eur Heart J*. 2020.

ESC 2025 guidelines on Pregnancy

2025 ESC Guidelines for the management of cardiovascular diseases and pregnancy. *Eur Heart J*. 2018.

Relevant Scientific Statements and Important Position Papers

European 2021 position paper on PFO

Decompression sickness, migraine, arterial deoxygenation syndromes and select high-risk clinical conditions. *Eur Heart J*. 2021; 42:1545-1553.

EHRA/HRS/APHRS/LAHRs 2022 Expert Consensus Statement on Genetic Testing

Expert Consensus Statement on the State of Genetic Testing for Cardiac Diseases. *Europace* 2022

ADULT CONGENITAL HEART DISEASE: GENERAL PRINCIPLES

Definition

Congenital heart disease refers to a defect in the structure of the heart and great vessels, which is present at birth (Table 1).^{1,2}

Epidemiology

Approximately 13.3 million people globally were living with congenital heart defects in 2019.³ Congenital heart disease constitutes the most common birth defect, with an incidence of approximately 9/1000 live births worldwide (12.3/1000 live births in the United States, and 6.9/1000 births in Europe).^{1,3} Up to 40% of them are cured spontaneously (mainly small VSDs), while with current surgical and interventional techniques 85% (56-98%) survive into adulthood (Adult Congenital Heart Disease-ACHD).⁴ Adult congenital heart disease comprises a population that has been estimated as at least 1.4 million in the USA, and 1.2 million in Europe, and admission rates in hospital are two times higher than in the general population.⁵⁻⁷ The majority of patients with congenital heart disease are adults,⁸ with up to 20% of them having severe CHD and >50% having ≥ 1 additional cardiovascular comorbidity.⁹ VSD, ASD and coarctation of the aorta are the most common defects.³ Congenital heart disease is the most common form of heart disease complicating pregnancy in the Western world (accounting for 74% of cases in the Canadian Cardiac Disease in Pregnancy [CARPREG] registry and 66% of cases in the European Registry on Pregnancy and Cardiac Disease [ROPAC] registry), whereas in less developed countries, rheumatic heart disease plays a larger role.¹⁰ There is also a growing number of elderly ACHD patients (>60 years) with high mortality rates and a higher utilization of healthcare resources compared with younger patients.¹¹

Rates of successful surgical repair and life expectancy for patients with congenital heart disease have increased dramatically in recent decades.¹² In the USA, mortality attributable to congenital heart disease throughout the lifespan has declined 39.4% over the past 19 years, with the highest mortality rate in infants (<1 year), but disparities in mortality were seen among racial/ethnic groups.¹³ In Sweden, the risk of mortality up to 68 years of age is >3 times higher compared with matched controls, but a notable decline in absolute and relative risk is noted for those born after 1975. On the basis of data from 3 US sites, most individuals with congenital heart disease survive to young adulthood,¹⁴ and at least 75% of

adult patients with congenital heart disease surviving to 18 years of age lived past middle age, becoming sexagenarians.¹⁵

Aetiology

The causes of congenital heart disease in humans remain undefined in the majority of cases, and probably depend on the interplay of multiple genetic and environmental factors. Disruption at any point during cardiac primary morphogenesis (ie ornatation of the heart tube, looping, septation, and resultant systemic and pulmonary circulations or a genetically abnormal placenta) results in the large spectrum of congenital heart defects. There has been evidence that an intrinsically angiogenic impairment exists in congenital heart disease, that appears to be present in both the maternal and foetal circulation and foetal heart.¹⁶ Epidemiological studies have suggested that a genetic or environmental cause can be identified in 20% to 30% of congenital cases.¹⁷

Environmental factors

They are rare causes of congenital heart disease (2%).¹⁷ Congenital rubella, maternal smoking, diabetes, hypertension, and connective tissue disorders, paternal exposure to phthalates, alcohol and drug abuse, air pollutants and pesticides.^{18 19} Weight control, smoking cessation and folic acid supplementation appear to decrease the risk of congenital heart disease in the offspring.¹⁰ Three specific subgroups of congenital heart defects, tetralogy of Fallot, double outlet right ventricle, and major ventricular septal defects, are associated with measures of impaired placental growth.²⁰

Genetic Factors

Genetic disorders may follow autosomal dominant, autosomal recessive, or X-linked inheritance patterns (Tables 2 and 3). Approximately 8% and 2% of cases are attributable to de novo autosomal dominant and inherited autosomal recessive variation, respectively.^{21,22}

Chromosomal disorders (8-10 % of congenital heart disease patients) caused by absent or duplicated chromosomes include trisomy 21 (Down syndrome), and 45X deletion (Turner syndrome).

Single-gene disorders (3-5% of congenital heart disease patients) are caused by gene deletions, duplications or mutations, in genes such as NKX2-5, GATA4, and TBX5.²³ Some examples are Holt-Oram syndrome, atrial septal defect with conduction abnormalities, tetralogy of Fallot, and supravalvular aortic stenosis.

Pathogenic copy number variants are found in of those with congenital heart disease as part of a syndrome, and in 3% to 10% among those with isolated congenital heart disease. The 22q11.2 deletion (DiGeorge syndrome-the most common microdeletion syndrome), and the Williams-Beuren syndrome are examples. The majority of cases (80%) occur as sporadic events, but in some, multiple family members are affected. In up to 31% of families in which

multiple relatives are affected by congenital heart disease, a genetic basis can be identified, and rapid screening for disease-related genes can be facilitated using advanced sequencing technologies.^{24,25}

Recurrence rate

The recurrence rate of congenital heart disease in offspring ranges from 3% to 50% and is higher when the mother rather than the father has congenital heart disease (Table 4). Diseases with a single gene disorder and/or chromosomal abnormalities are associated with a high recurrence rate. In autosomal dominant syndromes such as Marfan, Noonan, and Holt-Oram, there is a 50% risk of recurrence. For isolated cases of congenital heart disease without a family history of CHD (eg, sporadic defects), the recurrence risk of congenital heart disease in the offspring is, in average, 3% to 8%.¹⁰ The risk is higher if the mother is the affected parent or if more than one sibling is affected. Genetic counseling should be offered to all patients with congenital heart disease with referral for genetic testing on specific situations.

Congenital heart defects are more common in twins than in singletons, and the increased occurrence is not restricted to monochorionic twins. Thus, intrauterine surveillance and a postnatal comprehensive cardiac assessment for both twins may be considered regardless of chorionicity and zygosity.²⁶ First trimester screening can identify most fetal aneuploidies and structural abnormalities in the fetus.²⁷ Congenital heart defects in offspring may be an early marker of predisposition of the mother to cardiovascular disease.²⁸

Clinical Problems in ACHD

Patients with ACHD are afflicted by increased mortality compared to the general population as they grow older with leading causes of death being heart failure, pneumonia, sudden cardiac death, and cancer. Mortality is higher among patients with complex congenital heart disease, Fontan physiology, and Eisenmerger syndrome.²⁹ However, adults with lower complexity congenital heart disease (isolated septal or valve defects) are also at significant risk of acquiring cardiovascular morbidities relative to the general population.³⁰

Peripheral cyanosis may be due to peripheral vasoconstriction, polycythaemia, or poor cardiac output.

Central cyanosis (arterial saturation <85% or >5g reduced haemoglobin) may be due to right to left shunting or reduced pulmonary flow.

Differential cyanosis may be seen with PDA and pulmonary hypertension or interrupted aortic arch. In cyanosis from pulmonary causes there is an increase of PO₂ to at least >21 kPa (160 mmHg) after breathing 100% O₂ for 5 min. In patients with ACHD, cyanosis and chronic hypoxemia leads to marked erythrocytosis and, frequently, to low platelet counts (<100,000)

which may predispose to bleeding. The absence of erythrocytosis (e.g., hemoglobin >17.0 g/dl) in such patients suggests a "relative anemia".

Digital Clubbing. Apart from ACHD, it may be seen in pulmonary malignancy, chronic infection, and primary hypertrophic osteoarthropathy.

There are 3 conditions classified as **dextrocardia**: *mirror-image dextrocardia*, *dextroversion*, and *heart dextroposition*. The most common is mirror-image dextrocardia, in which the anterior-posterior relationships of the various parts of the heart are normal but their right-to-left orientation is reversed. The ECG is characterized by a negative P wave in lead I, and the QRS complexes in leads V₁ through V₆ indicate the activation of the ventricle in the right thorax (with diminishing QRS amplitude progression from V₁-V₆). Cardiac dextroversion refers to heart rotation into the right thorax, with its normal chambers and adjacency relations. There is a positive P wave in lead I, and the QRS complexes in leads V₁ through V₆ indicate the activation of the ventricle in the left thorax (with diminishing QRS amplitude progression from V₁-V₆). In dextroposition a normal heart is shifted to the right by some extracardiac factor, such as left lung hypoplasia (usually in the neonatal population) or fibrosis of the right lung. There are normal QRS complex in leads V₁ to V₆, with diminishing QRS amplitude progression from V₄ to V₆.³¹

Renal Function Sclerotic renal glomeruli leading to increased creatinine levels, proteinuria and hyperuricemia.

Gallstones Increased breakdown of red cells results in increased risk of calcium bilirubinate gallstones, especially in the cyanotic and Fontan populations.⁴

Hypertrophic osteoarthropathy with thickened periosteum and **scoliosis** that may compromise pulmonary function.

Cerebrovascular events (Embolic or hemorrhagic), **brain abscess**, **cognitive and psychological problems** are also common.

Pulmonary hypertension is not uncommon, and significantly affects morbidity and mortality (Tables 5 and 6). Cardiac catheterization is the only way to distinguish between pre- and post-capillary pulmonary hypertension and to measure PVR reliably, while other investigations are required to exclude other causes of pulmonary hypertension (e.g., lung disease and/or hypoxia, chronic thromboembolic disease).³² Moreover, pulmonary hypertension may also be simply related to high pulmonary blood flow in the presence a large left-to-right shunt, which may be difficult to appreciate on echocardiography.

Arrhythmias arise from the abnormal myocardial substrate due to variable pressure/volume loads and/or scars following cardiac surgery (Figure 1).³³⁻³⁵ They constitute the most common emergency in ACHD, accounting for 37% of emergency admissions.³⁶ Malignant arrhythmias typically become manifest the third decade of life.³⁴ Sudden cardiac death accounts for up to 25% of deaths in patients with congenital heart disease.³⁷ The risk of *atrial*

fibrillation in children and young adults with CHD is 22 times higher than that in matched control subjects, and patients with conotruncal defects have the highest risk. Up to the age of 42 years, 1 of 12 patients with congenital heart disease had developed AF, and 1 of 10 patients with congenital heart disease with AF had developed heart failure.³⁸ ***Atrial tachycardia*** (usually macro-reentrant) is often seen in tetralogy of Fallot, D-transposition, and following Fontan, Mustard and Senning procedures. ***Atrioventricular reentrant tachycardia*** (accessory pathways) in Ebstein's anomaly, and D- transposition. ***Ventricular tachycardia*** Conditions with the greatest known risk of late sudden cardiac death are tetralogy of Fallot, d- or l-transposition, aortic stenosis, and univentricular hearts.³⁹ ***Sick sinus syndrome*** in ASD, post-operatively Fontan, Mustard, Senning. ***AV block*** in ASD, corrected transposition, and after VSD closure or AVR. Congenital heart disease is an independent risk factor for the occurrence and outcome of **myocardial infarction**.⁴⁰

Risk of malignancy. Adults with congenital heart disease are exposed to increasing amounts of low-dose ionizing radiation from cardiac procedures. The cumulative incidence of cancer in adults with congenital heart disease between the ages of 18- and 64-years population is higher than in the general population and has been estimated 15%.⁴¹

Imaging Techniques and Investigations

Chest X-ray may reveal cardiac enlargement or disposition.

12-lead ECG is mandatory as well as **ambulatory electrocardiography** in patients at risk of arrhythmia.

Transthoracic echocardiography is mandatory as well as **ambulatory electrocardiography** in patients at risk of arrhythmia.

Two- or three-dimensional echocardiography with Doppler imaging and cardiac magnetic resonance (CMR) have now replaced cardiac catheterization as a diagnostic tool in most patients with ACHD (Table 7).¹ It is necessary for quantitative assessment of RV size and function and for the initial evaluation and serial assessment of selected patients.

CMR is considered superior to echocardiography for:

- Quantification of right ventricular (RV) volume and function, and pulmonary regurgitation (PR).

- Evaluation of the RVOT, RV-PA conduits, and great vessels.

- Evaluation of systemic and pulmonary veins (anomalous connection, obstruction, coronary venous anatomy pre-procedure, etc.)

- Tissue characterization (fibrosis, fat, iron, etc.).

CT is superior to CMR for:

Collaterals, arteriovenous malformations, and coronary anomalies.

Evaluation of intra- and extracardiac masses.

Coarctation of the aorta.

Haemodynamic Assessment

Haemodynamic measurements of cardiac output and systemic and pulmonary flow are derived by Doppler echocardiography that has replaced calculations by the Fick method. However, verification of pressures by direct measurement at cardiac catheterization is necessary for therapeutic decision making in the presence of pulmonary hypertension ($> \frac{1}{2}$ of systemic pressure), and for angiographic delineation of defects and selection of appropriate closure devices.

Pulmonary hypertension (PH) is defined as mean PAP > 20 mmHg (see also the section on Pulmonary Hypertension).

Pre-capillary PH is indicated by PAWP ≤ 15 mm Hg and PVR ≥ 3 WU,

Post-capillary PH by PAWP > 15 mm Hg and PVR < 3 WU) where PAWP: pulmonary artery wedge pressure and WU: Wood units.

Combined pre- and post-capillary PH is defined by PAWP > 15 mm Hg and PVR ≥ 3 WU.¹

Pulmonary vascular (arterial) resistance (PVR) is defined as

PA pressure - Wedge pressure / cardiac output.

Normal range: 0.25-1.5 Wood units (mm Hg/L/min) or 20-120 dynes/sec/cm⁵.

Systemic vascular (arterial) resistance (SVR) is defined as

Ao pressure – RA pressure / cardiac output.

Normal range: 9-20 Wood units (mm Hg/L/min) or 700-1600 dynes/sec/cm⁵.

If PVR $> \frac{2}{3}$ SVR, vasodilating challenge either acute in the catheter laboratory or chronic with oxygen, nitric oxide, adenosine, epoprostenol, calcium channel blockers, endothelin antagonists, or phosphodiesterase inhibitors, is indicated to investigate responsiveness of pulmonary vascular bed. With fixed values, irreversible damage and Eisenmerger syndrome have developed.

Pulmonary flow / Systemic flow (Qp/Qs)

It is now usually derived by echocardiography.

According to the Fick method, Qp/Qs is calculated by oximetry as:

$$Qp/Qs = \frac{Ao \text{ saturation} - \text{mixed venous saturation}}{PV-PA \text{ saturation}}$$
 where mixed venous saturation = $(3 \times SVC \text{ saturation} + IVC \text{ saturation})/4$

If PV saturation is not available, the value of 98 is used instead.

Routine **saturation run** during catheterization for exclusion of shunt involves blood sampling from:

High SVC, RA/SVC junction, high RA, mid RA, low RA, IVC, RV inflow, RV body, RV outflow, main PA, PV and LA if possible, LV, and Ao.

A step-up of saturation > 10% indicates shunt.

Coronary Angiography

Coronary angiography or computed coronary angiography in low or intermediate pretest probability,⁴ is indicated pre-operatively in patients >40 years, postmenopausal women, adults with multiple risk factors for coronary artery disease and children with suspicion of congenital coronary anomalies. In patients with a low or intermediate pretest probability of coronary artery disease, CT coronary angiography may be used.

Exercise testing

In symptomatic patients with ACHD, a 6-minute walk test is useful to objectively assess symptom severity, functional capacity, and response to therapy (Table 8).

Cardiopulmonary exercise testing provides strong prognostic information in adult patients with congenital heart disease. Peak oxygen consumption (VO₂) is one of the best predictors of morbidity and mortality.⁴² The presence of chronotropic incompetence on **conventional exercise testing** is a predictor of pregnancy outcome.¹⁰

Spirometry

There is a high prevalence of markedly abnormal forced vital capacity (FVC) in patients with ACHD, and reduced FVC is associated with increased mortality.⁴³

Biochemistry

Elevated levels of **biomarkers** such as NT-proBNP, high-sensitive troponin-T, and growth-differentiation factor 15, identify patients at highest risk of cardiovascular events.⁴⁴

Albuminuria is common and is associated with increased risk for adverse outcome in patients with ACHD.⁴⁵

Assessment of Arrhythmia

Surveillance for adults with moderate or severe CHD should include a **12-lead ECG** at least once per year, and periodic **Holter** monitoring in adults with transposition of the great arteries and atrial switch surgery, Fontan palliation, and in patients with tetralogy of Fallot >35 years of age.^{18 36}

Electrophysiologic testing may be useful in patients with unexplained syncope,⁴⁶ and “high-risk” substrates associated with primary ventricular arrhythmias or poorly tolerated atrial tachyarrhythmias, such as tetralogy of Fallot, transposition of the great arteries with atrial switch surgery, or significant systemic or single ventricular dysfunction.⁴⁶ Programmed ventricular stimulation may also be useful in risk stratifying adults with tetralogy of Fallot who have additional risk factors for sudden cardiac death.³³ Prior to cardiac surgery, EPS is indicated in the presence of history of syncope, VT, SVT (not AF) and ventricular

preexcitation. It may also be considered in patients with a history of palpitations or nonsustained atrial or ventricular arrhythmias, and in cases known to be at high risk for atrial arrhythmia development.³³

Principles of Therapy

ACHD programs and clinicians who care for adults with congenital heart disease should follow policies and procedures that reduce barriers, reduce attrition, and improve access to lifelong ACHD care (ACC/AHA 2025 GL on ACHD 1 B-NR). All patients with congenital heart disease should receive structured, patient-centered transition education that is age-, sex-, gender-, and developmentally appropriate to improve knowledge (ACC/AHA 2025 GL on ACHD 1 A) and reduce loss to care (ACC/AHA 2025 GL on ACHD 1 B-NR). Congenital heart disease programs and clinicians should have transfer-of-care policies and procedures to ensure effective handoffs of patients from a pediatric to an ACHD cardiologist (ACC/AHA 2025 GL on ACHD 1 B-NR). General recommendations are offered in Table 8.^{1,47,48}

Practical guidance from pre-conception through postpartum for cardiovascular conditions that are predominantly congenital or heritable in nature have also been provided by an ACC Committee.⁴⁹ Specific management is discussed in relevant chapters. In neonates who undergo cardiac surgery, optimal early outcomes are associated with delivery at 39 to 40 weeks gestation. Birth during the early term period of 37 to 38 weeks' gestation is associated with worse outcomes after neonatal cardiac surgery.⁵⁰ The IMPACT (Improving Pediatric and Adult Congenital Treatment) database that was launched by the National Cardiovascular Data Registry (NCDR), provides measures and predictors of procedural success that may be considered in evaluating patients with congenital heart disease for common interventional procedures. Procedures directed at PDA and ASD closure are among the safest and most successful procedures for congenital heart disease in the US compared with aortic valvuloplasty and coarctation angioplasty and/or stenting, which are generally less successful and are associated with greater risk.⁵¹ Following major treatment advances during the past 50 years, surgical correction of nearly all congenital heart defects is now possible, and substantial improvements in short-term survival have been documented for most conditions with early survival approaching 100% and 10-year survival more than 90%.⁵²⁻⁵⁴ Survival after operation is better in patients without heterotaxy, ie randomized variation in the left-right asymmetry of visceral organs that differs from complete situs solitus and situs inversus, probably due to ciliary dysfunction that is associated with heterotaxy.⁵⁵ Obesity and underweight BMI are associated with increased risk of adverse outcome.⁵⁶ Heart transplantation is an established therapy option for patients with end-stage heart failure.⁵⁷ The

Residual Lesion Score (RLS) is a tool for assessing surgical results based upon post-operative echocardiographic findings and unplanned surgical or catheter-based reinterventions prior to discharge in the anatomic areas that were manipulated at surgery.⁵⁸

Haematologic problems

Phlebotomy should be undertaken with hemoglobin > 20 g/dl and Hct > 65%, associated with headache, increasing fatigue, or other symptoms of hyperviscosity in the absence of dehydration or anemia under careful volume replacement with normal saline. Multiple phlebotomies result in iron deficiency that is associated with impaired small-vessel blood flow, and an increase in the risk of reversible ischemic neurologic deficits and stroke. The use of anticoagulation and antiplatelet agents is controversial and should be confined to well-defined indications. The experience with NOACs is limited in ACHD patients.⁵⁹

Cyanosis

General rules are:^{1,48}

- Avoid dehydration and air contamination.
- Treat iron deficiency anemia with iron
- Adjustment of anticoagulation in patients with haematocrit >55%.
- Allopurinol treatment in patients with high serum acid levels and a history of gout.
- Non-estrogen containing birth control (intrauterine device may be an option).
- Pregnancy is avoided if arterial oxygen saturation <90%

Patients with cyanosis can travel safely on commercial airlines.

Recommendations are provided in Table 9 and Figure 2.

Bradycardias

The most common indications for permanent pacemaker implantation in children, adolescents, and patients with congenital heart disease are symptomatic sinus bradycardia, the bradycardia- tachycardia syndromes, and advanced second- or third-degree AV block, either congenital or postsurgical.⁶⁰ Indications for pacing are presented in Table 10 and the relevant Chapter on Bradycardias.

Tachycardias

Rhythm control is typically preferred over rate control for atrial arrhythmias in complex patients, such as those with a systemic right ventricle or Fontan circulation.² Atrial and ventricular tachycardias can be treated with catheter ablation usually assisted by electroanatomic mapping.^{33,35} Procedural success is high but recurrence rate is more than 50% in two years.⁶¹ Recommendations for anticoagulation are provided in Chapter on AF. The experience with NOACs is limited.⁵⁹ Recommendations for ICD are not, in general, different than that to other patients with cardiac disease. Recommendations on specific arrhythmias as well as indications for ICD are provided in Tables 11 and 12, and Figures 3 and 4, as well as in relevant Chapters.

Hypertension

In the treatment of the hypertensive patient with cyanotic ACHD, ACE inhibitors, angiotensin receptor blockers, and diuretic agents should be used cautiously, and care should be coordinated at an ACHD center.⁴

Pulmonary Hypertension

Remodeling of the pulmonary vasculature in patients with congenital heart disease results in pulmonary arterial hypertension that has initially a reversible and eventually an irreversible stage.⁶² At his final stage, recent therapeutic interventions may improve the outcome, mainly by delaying disease progression, but reversal or cure has not yet been achieved.

Recommendations are presented in Chapters on PH.

Heart Failure

Despite optimal medical and surgical treatment, many patients experience a progressive decline in cardiopulmonary function leading to advanced heart failure (Tables 13 and 14). Severe ventricular dysfunction and/or pulmonary hypertension may not be amenable to corrective repair. Heart transplantation with or without mechanical circulatory support may be the only option for highly selected patients (Table 15).⁶³ See also Chapters on HF.

Psychosocial issues and sexual dysfunction

Individual and family psychosocial screening should be part of the care of ACHD patients.⁴ Phosphodiesterase 5 inhibitors are safe provided the patient is not taking nitrates. The effectiveness of these drugs has not been established in the presence of severe ventricular outflow tract obstruction. Dyspareunia in women should be treated with nonsystemic estrogen therapy, which has not been shown to increase cardiovascular risk.⁴

Non-cardiac surgery

Preoperative evaluation and surgery for patients with congenital heart disease should be performed in specializing centers with experienced surgeons and cardiac anesthesiologists (AHA/ACC 2025 GL on ACHD, I B-NR, ESC 2022 GL on noncardiac surgery, I C).

Recommendations are provided in Table 16.

Endocarditis Prophylaxis

The risk of endocarditis in patients with ACHD is estimated to 4.1 first cases/10 000 person-years. The greatest risk is seen in children with cyanotic CHD, endocardial cushion defects, or left-sided lesions, and recent cardiac surgery and young age.⁶⁴ In a recent study, valve-containing prosthetics were the main determinant of endocarditis risk whereas other prosthetics, including valve-repair, were not associated with increased risk long term after implantation.⁶⁵ Prophylaxis is indicated only in high risk patients, and only before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa, or before vaginal delivery.¹ Congenital conditions for which

endocarditis prophylaxis is recommended before the aforementioned procedures are patients with:¹

- Previous IE
- Prosthetic valves (biological and mechanical, surgical and transcatheter valves, especially Melody)
- Valve repairs using prosthetic ring
- Within 6 months of placement of prosthetic material (particular bovine jugular vein conduits)
- Residual intracardiac shunts at the site of or adjacent to previous repair with prosthetic material or devices
- Uncorrected cyanotic heart disease.

A detailed discussion and specific recommendations are provided in the Chapter on infective endocarditis.

Genetic Testing

New techniques such as chromosomal microarray and Next Generation DNA Sequencing (NGS) have facilitated genetic testing, allowing a rapid pace of discovery of new genes for congenital heart disorders.¹⁷ Detailed family history for congenital heart disease and other birth defects that spans at least 3 generations is recommended to identify familial inheritance. Patients with a history of parental consanguinity or a family history of congenital heart disease that includes frequent miscarriages or stillbirths should be referred for genetic evaluation. Genetic evaluation may be useful in patients with associated clinical features suggestive of an underlying genetic syndrome, such as facial dysmorphism, extracardiac malformations, cognitive impairment, neuropsychiatric disorders, or multisystem involvement (eg, hepatic, renal, hematologic, immunologic, endocrinologic, and sensorineural abnormalities) (Tables 17 and 18). Genetic testing is also reasonable in patients with certain types of isolated cardiac defects commonly associated with genetic syndromes even in the absence of syndromic features.²² Common examples are screening for 22q11 deletions for patients with conotruncal cardiac defects such as interrupted aortic arch, Tetralogy of Fallot, VSD with aortic arch anomaly, right aortic arch, or discontinuous branch PAs and screening for 7q11.23 deletion or Williams-Beuren syndrome in patients with supravalvar AS, coronary stenosis, and supravalvar and peripheral pulmonary stenosis.^{4,22}

Exercise

Adults with congenital heart disease have subnormal exercise tolerance. However, participation in regular exercise is beneficial for fitness and psychological well-being.⁶⁶ and, especially in children with congenital heart defects 2-18 years old, sudden cardiac death is

infrequent, and rarely occurs during physical activity.⁶⁷ There is no evidence regarding whether or not there is a need to restrict recreational physical activity among patients with congenital heart defects, apart from those with rhythm disorders. Counseling to encourage daily participation in appropriate physical activity should be a core component of every patient encounter (Table 19 and Figure 5).

As a general recommendation, dynamic exercise is more suitable than static exercise.

Conditions that are not compatible with competitive sports are:

- Eisenmenger syndrome
- Pulmonary hypertension
- Univentricular heart physiology
- Ebstein's anomaly
- Transposition of great arteries
- Coronary artery anomalies

Maximal exercise testing is contraindicated in all patients with pulmonary hypertension.

In general, patients should be counseled about the types and intensity of exercise appropriate to their clinical status, especially under guidance by cardiopulmonary exercise testing. Participation in regular moderate exercise is recommended for all individuals with ACHD (ESC 2020 GL on Sports, I B), and cardiac rehabilitation is also recommended to increase exercise capacity. Competitive sports are not recommended for individuals with CHD who are in NYHA class III/IV or with potentially serious arrhythmias (ESC 2020 GL on Sports, III C). More detailed recommendations have also been provided,^{68,69} and specific recommendations for athletes with individual disease entities are discussed in the relevant Chapters.

Long-distance Flights

Cyanotic patients should use only pressurized commercial airplanes and should drink nonalcoholic and noncaffeinated fluids frequently on long-distance flights to avoid dehydration. Oxygen therapy, although often unnecessary, may be suggested for prolonged travel in cyanotic patients. Similarly, residence at high altitude is detrimental for patients with cyanosis.

Pregnancy

Most pregnant patients with ACHD can undergo vaginal delivery safely, with appropriate risk stratification and monitoring.² Patients at high risk of maternal morbidity or mortality, including women with pulmonary arterial hypertension, Eisenmenger syndrome, severe systemic ventricular dysfunction, and/or severe left-sided obstructive lesions should be counseled against becoming pregnant or be given the option of terminating pregnancy.⁷⁰ In

women with congenital defects not complicated by Eisenmenger syndrome, and without significant pulmonary hypertension or Marfan, Ehlers-Danlos or Loeys-Dietz syndromes with aortic root > 45 mm, pregnancy can be tolerated.^{71,72} Uteroplacental Doppler flow parameters are abnormal in pregnant women with CHD, and are related to offspring outcome.⁷³ Maternal defect complexity, arterial hypertension, heart failure, prior fertility treatment, and anticoagulation with vitamin K antagonists are significant predictors of adverse neonatal outcome.⁷⁴

The initial diagnostic evaluation includes measurement of arterial oxygen saturation, electrocardiogram, and echocardiogram.⁷² A three-generation family history, including any consanguinity, should be completed. Genetic evaluation should be made available to all women with congenital heart disease to determine recurrence, particularly in those patients with a family history of congenital heart disease and those with possible autosomal dominant lesions (e.g., 22q 11 deletion).⁷² The most prevalent cardiac complications during pregnancy are arrhythmias and heart failure and hypertensive complications. Estrogen-only contraceptive pills potentially increase the thrombotic risk and should be avoided. The ACC/AHA recommendations, as well as the ESC guidelines on pregnancy are presented in Tables 20 and 21. Recommendations on arrhythmias are presented in Figure 6.

References

1. Baumgartner H, et al. 2020 ESC Guidelines for the management of adult congenital heart disease. *Eur Heart J*. 2020. doi: 10.1093/eurheartj/ehaa554

2. Gurvitz M, et al. 2025 ACC/AHA/HRS/ISACHD/SCAI Guideline for the Management of Adults With Congenital Heart Disease: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *Journal of the American College of Cardiology*. 2025. doi: 10.1016/j.jacc.2025.09.006
3. Palaniappan LP, et al. 2026 Heart Disease and Stroke Statistics: A Report of US and Global Data From the American Heart Association. *Circulation*. 2026;153:e275-e906. doi: 10.1161/CIR.0000000000001412
4. Bhatt AB, et al. Congenital heart disease in the older adult: a scientific statement from the American Heart Association. *Circulation*. 2015;131:1884-1931. doi: 10.1161/CIR.0000000000000204
5. Gilboa SM, et al. Congenital Heart Defects in the United States: Estimating the Magnitude of the Affected Population in 2010. *Circulation*. 2016;134:101-109. doi: 10.1161/CIRCULATIONAHA.115.019307
6. Verheugt CL, et al. The emerging burden of hospital admissions of adults with congenital heart disease. *Heart*. 2010;96:872-878. doi: 10.1136/hrt.2009.185595
hrt.2009.185595 [pii]
7. Liu Y, et al. Global birth prevalence of congenital heart defects 1970-2017: updated systematic review and meta-analysis of 260 studies. *Int J Epidemiol*. 2019;48:455-463. doi: 10.1093/ije/dyz009
8. Marelli AJ, et al. Lifetime prevalence of congenital heart disease in the general population from 2000 to 2010. *Circulation*. 2014;130:749-756. doi: 10.1161/CIRCULATIONAHA.113.008396
9. Gurvitz M, et al. Characteristics of Adults With Congenital Heart Defects in the United States. *JACC*. 2020.
10. Brickner ME. Cardiovascular management in pregnancy: congenital heart disease. *Circulation*. 2014;130:273-282. doi: 10.1161/CIRCULATIONAHA.113.002105
11. Tutarel O, et al. Congenital heart disease beyond the age of 60: emergence of a new population with high resource utilization, high morbidity, and high mortality. *Eur Heart J*. 2014;35:725-732. doi: 10.1093/eurheartj/ehd257
12. Brida M, et al. Acquired cardiovascular disease in adults with congenital heart disease. *Eur Heart J*. 2023;44:4533-4548. doi: 10.1093/eurheartj/ehad570
13. Lopez KN, et al. US Mortality Attributable to Congenital Heart Disease Across the Lifespan From 1999 Through 2017 Exposes Persistent Racial/Ethnic Disparities. *Circulation*. 2020;142:1132-1147. doi: 10.1161/CIRCULATIONAHA.120.046822
14. Downing KF, et al. Survival From Birth Until Young Adulthood Among Individuals With Congenital Heart Defects: CH STRONG. *Circulation*. 2023;148:575-588. doi: 10.1161/CIRCULATIONAHA.123.064400
15. Dellborg M, et al. Adults With Congenital Heart Disease: Trends in Event-Free Survival Past Middle Age. *Circulation*. 2023;147:930-938. doi: 10.1161/CIRCULATIONAHA.122.060834
16. Llurba E, et al. Maternal and foetal angiogenic imbalance in congenital heart defects. *Eur Heart J*. 2014;35:701-707. doi: 10.1093/eurheartj/ehd389
17. Pierpont ME, et al. Genetic Basis for Congenital Heart Disease: Revisited. A Scientific Statement From the American Heart Association. *Circulation*. 2018. doi: 10.1161/CIR.0000000000000606]
18. Vinet E, et al. Increased congenital heart defects in children born to women with systemic lupus erythematosus: results from the offspring of Systemic Lupus Erythematosus Mothers Registry Study. *Circulation*. 2015;131:149-156. doi: 10.1161/CIRCULATIONAHA.114.010027
19. Liu S, et al. Association between maternal chronic conditions and congenital heart defects: a population-based cohort study. *Circulation*. 2013;128:583-589. doi: 10.1161/CIRCULATIONAHA.112.001054
20. Matthiesen NB, et al. Congenital Heart Defects and Indices of Placental and Fetal Growth in a Nationwide Study of 924 422 Liveborn Infants. *Circulation*. 2016;134:1546-1556. doi: 10.1161/CIRCULATIONAHA.116.021793
21. Jin SC, et al. Contribution of rare inherited and de novo variants in 2,871 congenital heart disease probands. *Nat Genet*. 2017;49:1593-1601. doi: 10.1038/ng.3970
22. Wilde AAM, et al. European Heart Rhythm Association (EHRA)/Heart Rhythm Society (HRS)/Asia Pacific Heart Rhythm Society (APHRS)/Latin American Heart Rhythm Society (LAHRS) Expert Consensus Statement on the state of genetic testing for cardiac diseases. *Europace*. 2022. doi: 10.1093/europace/euac030
23. Su W, et al. Congenital heart diseases and their association with the variant distribution features on susceptibility genes. *Clinical genetics*. 2016. doi: 10.1111/cge.12835
24. Blue GM, et al. Targeted next-generation sequencing identifies pathogenic variants in familial congenital heart disease. *Journal of the American College of Cardiology*. 2014;64:2498-2506. doi: 10.1016/j.jacc.2014.09.048
25. Blue GM, et al. Advances in the Genetics of Congenital Heart Disease. A Clinician's Guide. *Journal of the American College of Cardiology*. 2017;69:859-870. doi: 10.1016/j.jacc.2016.11.060
26. Herskind AM, et al. Increased prevalence of congenital heart defects in monozygotic and dizygotic twins. *Circulation*. 2013;128:1182-1188. doi: 10.1161/CIRCULATIONAHA.113.002453
27. Jicinska H, et al. Does First-Trimester Screening Modify the Natural History of Congenital Heart Disease? Analysis of Outcome of Regional Cardiac Screening at 2 Different Time Periods. *Circulation*. 2017;135:1045-1055. doi: 10.1161/CIRCULATIONAHA.115.020864

28. Auger N, et al. Long-Term Risk of Cardiovascular Disease in Women Who Have Had Infants With Heart Defects. *Circulation*. 2018. doi: 10.1161/CIRCULATIONAHA.117.030277
29. Diller GP, et al. Survival Prospects and Circumstances of Death in Contemporary Adult Congenital Heart Disease Patients Under Follow-Up at a Large Tertiary Centre. *Circulation*. 2015;132:2118-2125. doi: 10.1161/CIRCULATIONAHA.115.017202
30. Saha P, et al. Substantial Cardiovascular Morbidity in Adults With Lower-Complexity Congenital Heart Disease. *Circulation*. 2019;139:1889-1899. doi: 10.1161/CIRCULATIONAHA.118.037064
31. Chang Q, et al. Bundle Branch Block Site in a Patient With a Right-Lying Heart and Wide QRS Complex. *JAMA Intern Med*. 2018. doi: 10.1001/jamainternmed.2018.6709
32. Dimopoulos K, et al. Echocardiographic Screening for Pulmonary Hypertension in Congenital Heart Disease. *JACC*. 2018.
33. Khairy P, et al. PACES/HRS Expert Consensus Statement on the Recognition and Management of Arrhythmias in Adult Congenital Heart Disease. *Heart rhythm : the official journal of the Heart Rhythm Society*. 2014;11:e102-165. doi: 10.1016/j.hrthm.2014.05.009
34. Walsh EP. Sudden death in adult congenital heart disease: risk stratification in 2014. *Heart rhythm : the official journal of the Heart Rhythm Society*. 2014;11:1735-1742. doi: 10.1016/j.hrthm.2014.07.021
35. Hernandez-Madrid A, et al. Arrhythmias in congenital heart disease: a position paper of the European Heart Rhythm Association (EHRA), Association for European Paediatric and Congenital Cardiology (AEPCC), and the European Society of Cardiology (ESC) Working Group on Grown-up Congenital heart disease, endorsed by HRS, PACES, APHRS, and SOLAECE. *Europace*. 2018. doi: 10.1093/europace/eux380
36. Chessa M, et al. Emergency department management of patients with adult congenital heart disease: a consensus paper from the ESC Working Group on Adult Congenital Heart Disease, the European Society for Emergency Medicine (EUSEM), the European Association for Cardio-Thoracic Surgery (EACTS), and the Association for Acute Cardiovascular Care (ACVC). *Eur Heart J*. 2021;42:2527-2535. doi: 10.1093/eurheartj/ehab272
37. Khairy P, et al. Sudden cardiac death in congenital heart disease. *Eur Heart J*. 2022;43:2103-2115. doi: 10.1093/eurheartj/ehac104
38. Mandalenakis Z, et al. Atrial Fibrillation Burden in Young Patients with Congenital Heart Disease. *Circulation*. 2017. doi: 10.1161/CIRCULATIONAHA.117.029590
39. Bessière F. Ventricular Arrhythmias in Adults With Congenital Heart Disease, Part I. . *JACC*. 2023;82:1108–1120.
40. Fedchenko M, et al. Long-term outcomes after myocardial infarction in middle-aged and older patients with congenital heart disease-a nationwide study. *Eur Heart J*. 2021;42:2577-2586. doi: 10.1093/eurheartj/ehaa874
41. Cohen S, et al. Exposure to Low-Dose Ionizing Radiation from Cardiac Procedures and Malignancy Risk in Adults with Congenital Heart Disease. *Circulation*. 2017. doi: 10.1161/CIRCULATIONAHA.117.029138
42. Inuzuka R, et al. Comprehensive use of cardiopulmonary exercise testing identifies adults with congenital heart disease at increased mortality risk in the medium term. *Circulation*. 2012;125:250-259. doi: 10.1161/CIRCULATIONAHA.111.058719
- CIRCULATIONAHA.111.058719 [pii]
43. Alonso-Gonzalez R, et al. Abnormal lung function in adults with congenital heart disease: prevalence, relation to cardiac anatomy, and association with survival. *Circulation*. 2013;127:882-890. doi: 10.1161/CIRCULATIONAHA.112.126755
44. Baggen VJ, et al. Prognostic Value of N-Terminal Pro-B-Type Natriuretic Peptide, Troponin-T, and Growth-Differentiation Factor 15 in Adult Congenital Heart Disease. *Circulation*. 2016. doi: 10.1161/CIRCULATIONAHA.116.023255
45. Rajpal S, et al. Association of Albuminuria With Major Adverse Outcomes in Adults With Congenital Heart Disease. Results From the Boston Adult Congenital Heart Biobank. *JAMA Cardiol*. 2018. doi: 10.1001/jamacardio.2018.0125
46. Shen WK, et al. 2017 ACC/AHA/HRS Guideline for the Evaluation and Management of Patients With Syncope: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. *Journal of the American College of Cardiology*. 2017;70:620-663. doi: 10.1016/j.jacc.2017.03.002
47. Mylotte D ea. Specialized Adult Congenital Heart Disease Care: The Impact of Policy on Mortality. *Circulation*. 2014.
48. Stout KK, et al. 2018 AHA/ACC Guideline for the Management of Adults With Congenital Heart Disease: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Journal of the American College of Cardiology*. 2018. doi: 10.1016/j.jacc.2018.08.1028
49. Lindley KJ, et al. Management of Women With Congenital or Inherited Cardiovascular Disease From Pre-Conception Through Pregnancy and Postpartum: JACC Focus Seminar 2/5. *Journal of the American College of Cardiology*. 2021;77:1778-1798. doi: 10.1016/j.jacc.2021.02.026
50. Costello JM, et al. Gestational age at birth and outcomes after neonatal cardiac surgery: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. *Circulation*. 2014;129:2511-2517. doi: 10.1161/CIRCULATIONAHA.113.005864

51. Moore JW, et al. Procedural results and safety of common interventional procedures in congenital heart disease: initial report from the National Cardiovascular Data Registry. *Journal of the American College of Cardiology*. 2014;64:2439-2451. doi: 10.1016/j.jacc.2014.09.045
52. Raissadati A, et al. Progress in late results among pediatric cardiac surgery patients: a population-based 6-decade study with 98% follow-up. *Circulation*. 2015;131:347-353; discussion 353. doi: 10.1161/CIRCULATIONAHA.114.011190
53. Erikssen G, et al. Achievements in congenital heart defect surgery: a prospective, 40-year study of 7038 patients. *Circulation*. 2015;131:337-346; discussion 346. doi: 10.1161/CIRCULATIONAHA.114.012033
54. Larsen SH, et al. Interventional Treatment of Patients With Congenital Heart Disease. Nationwide Danish Experience Over 39 Years. *Journal of the American College of Cardiology*. 2017. doi: 10.1016/j.jacc.2017.03.587
55. Nakhleh N, et al. High prevalence of respiratory ciliary dysfunction in congenital heart disease patients with heterotaxy. *Circulation*. 2012;125:2232-2242. doi: 10.1161/CIRCULATIONAHA.111.079780
CIRCULATIONAHA.111.079780 [pii]
56. O'Byrne ML, et al. Effect of Obesity and Underweight Status on Perioperative Outcomes of Congenital Heart Operations in Children, Adolescents, and Young Adults: An Analysis of Data From the Society of Thoracic Surgeons Database. *Circulation*. 2017;136:704-718. doi: 10.1161/CIRCULATIONAHA.116.026778
57. Cohen S, et al. Temporal trends and changing profile of adults with congenital heart disease undergoing heart transplantation. *Eur Heart J*. 2016;37:783-789. doi: 10.1093/eurheartj/ehv628
58. Nathan M, et al. Impact of Major Residual Lesions on Outcomes After Surgery for Congenital Heart Disease. *JACC*. 2021.
59. Freisinger E, et al. Current use and safety of novel oral anticoagulants in adults with congenital heart disease: results of a nationwide analysis including more than 44 000 patients. *Eur Heart J*. 2020. doi: 10.1093/eurheartj/ehaa844
60. Sherwin ED, et al. Update on interventional electrophysiology in congenital heart disease: evolving solutions for complex hearts. *Circulation Arrhythmia and electrophysiology*. 2013;6:1032-1040. doi: 10.1161/CIRCEP.113.000313
61. Brouwer C, et al. Contemporary Patients With Congenital Heart Disease: Uniform Atrial Tachycardia Substrates Allow for Clear Ablation End Points With Improved Long-Term Outcome. *Circulation: Arrhythmia and Electrophysiology*. 2021.
62. van der Feen DE, et al. Pulmonary arterial hypertension in congenital heart disease: translational opportunities to study the reversibility of pulmonary vascular disease. *Eur Heart J*. 2017. doi: 10.1093/eurheartj/ehx034
63. Givertz MM, et al. Advanced Heart Failure Therapies for Adults With Congenital Heart Disease. *JACC*. 2019.
64. Rushani D, et al. Infective endocarditis in children with congenital heart disease: cumulative incidence and predictors. *Circulation*. 2013;128:1412-1419. doi: 10.1161/CIRCULATIONAHA.113.001827
65. Kuijpers JM, et al. Incidence, risk factors, and predictors of infective endocarditis in adult congenital heart disease: focus on the use of prosthetic material. *Eur Heart J*. 2017. doi: 10.1093/eurheartj/ehw591
66. Budts W, et al. Physical activity in adolescents and adults with congenital heart defects: individualized exercise prescription. *Eur Heart J*. 2013;34:3669-3674. doi: 10.1093/eurheartj/ehv433
67. Jortveit J, et al. Sudden unexpected death in children with congenital heart defects. *Eur Heart J*. 2016;37:621-626. doi: 10.1093/eurheartj/ehv478
68. Pelliccia A, et al. 2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease. *Eur Heart J*. 2020. doi: 10.1093/eurheartj/ehaa605
69. Budts W, et al. Recommendations for participation in competitive sport in adolescent and adult athletes with Congenital Heart Disease (CHD): position statement of the Sports Cardiology & Exercise Section of the European Association of Preventive Cardiology (EAPC), the European Society of Cardiology (ESC) Working Group on Adult Congenital Heart Disease and the Sports Cardiology, Physical Activity and Prevention Working Group of the Association for European Paediatric and Congenital Cardiology (AEPC). *Eur Heart J*. 2020. doi: 10.1093/eurheartj/ehaa501
70. De Backer J, et al. 2025 ESC Guidelines for the management of cardiovascular disease and pregnancy. *Eur Heart J*. 2025. doi: 10.1093/eurheartj/ehaf193
71. Greutmann M, et al. Pregnancy in women with congenital heart disease. *Eur Heart J*. 2015;36:2491-2499. doi: 10.1093/eurheartj/ehv288
72. Canobbio MM, et al. Management of Pregnancy in Patients With Complex Congenital Heart Disease: A Scientific Statement for Healthcare Professionals From the American Heart Association. *Circulation*. 2017. doi: 10.1161/CIR.0000000000000458
73. Pieper PG, et al. Uteroplacental blood flow, cardiac function, and pregnancy outcome in women with congenital heart disease. *Circulation*. 2013;128:2478-2487. doi: 10.1161/CIRCULATIONAHA.113.002810
74. Lammers AE, et al. Maternal and neonatal complications in women with congenital heart disease: a nationwide analysis. *Eur Heart J*. 2021;42:4252-4260. doi: 10.1093/eurheartj/ehab571

