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# Special considerations in the management of adult congenital heart disease

Patients with adult CHD who experience pregnancy-related cardiovascular disease, pulmonary arterial hypertension, or arrhythmias can benefit from the help of a multidisciplinary care team and advances in imaging technology.

ABSTRACT: Special considerations for the management of adult congenital heart disease include pregnancy-related cardiovascular disease, pulmonary arterial hypertension, and arrhythmias. Improvements in the treatment of congenital heart disease mean that more women with congenital heart disease are reaching childbearing age. In BC the Cardiac Obstetrics clinic at St. Paul's Hospital provides coordinated care for pregnant women with cardiac conditions. The clinic also offers preconception counseling so that couples can make informed choices about pregnancy. Another service based at St. Paul's Hospital, the Pacific Adult Congenital Heart clinic, helps manage patients with pulmonary arterial hypertension, a progressive condition affecting around 10% of adult congenital heart disease patients. Agents used to treat pulmonary arterial hypertension include endothelin receptor antagonists and phosphodiesterase type 5 inhibitors. The Pacific Adult Congenital Heart clinic also manages

patients with a significant arrhythmia, often the first manifestation of deterioration in complex congenital heart disease. Complications that can result from arrhythmias include heart failure, thromboembolism, and sudden cardiac death. A range of complementary imaging modalities aid in the management of all these conditions by enabling the assessment of ventricular and valvular function (echocardiography and magnetic resonance imaging), quantification of right ventricular volume (multidetector computed tomography), and exclusion of coronary stenosis (coronary CT angiography).

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Complications in adult congenital heart disease (CHD) include pregnancy-related cardiovascular disease (CVD), pulmonary arterial hypertension (PAH), and arrhythmias. Patients with these complications can benefit from a variety of treatments and management approaches. They can also benefit from advances in diagnostic imaging.

## Pregnancy-related CVD

At present, 0.2% to 4.0% of all pregnancies in Western industrialized countries are complicated by cardiovascular disease, and the number of patients who develop cardiac

complications during pregnancy is increasing.[1] This is a unique circumstance where management for optimal outcome needs to consider both the mother and the fetus. The only current guidelines for managing CVD during pregnancy[2] emphasize the following aspects of care:

• Counseling and managing women of childbearing age with suspected cardiac disease should start before pregnancy occurs.
• Pregnant women with CVD should be managed by specialized interdisciplinary teams.
• High-risk patients should be treated in specialized centres.
• Diagnostic procedures and interventions should be performed by specialists with expertise in managing pregnant patients.

The nature of CVD in pregnancy differs from one country to another. In Western countries, the risk of acquired CVD in pregnancy has increased because of greater age at first pregnancy and growing rates of diabetes, hypertension, and obesity. Also, the treatment of congenital heart disease has improved, resulting in more women with CHD reaching childbearing age.[3] In Western coun-

tries heart disease is now the major cause of maternal death during pregnancy.[4]

Pregnancy induces changes in the cardiovascular system to meet the increased metabolic demands of the mother and fetus. These changes include increases in blood volume and cardiac output, and reductions in systemic vascular resistance and blood pressure. Along with other physiological demands of pregnancy, these changes are variably tolerated by women with CVD, and in some cases pregnancy should be avoided. There are many tools available to determine the cardiovascular risk of pregnancy in women with CVD.[5,6] Certainly the World Health Organization (WHO) classification of maternal cardiovascular risk[2] is the most straightforward and helps to stratify pregnancy risk in a broad sense.[7] A more granular risk assessment can be made using risk scores and lesion-specific research data.

### Obstetric care

A special multidisciplinary team for the care of pregnant women with CVD operates at St. Paul's Hospital in collaboration with BC Wom-

en's Hospital (**Figure 1**). The Cardiac Obstetric (COB) clinic, the first of its kind in Western Canada, was established 15 years ago to serve the growing number of women with cardiac conditions who require specialized cardiac and obstetric care. This clinic sees patients once a week and is attended by one of two designated cardiologists, the maternity clinical nurse specialist, and the COB nurse patient educator. This is also a teaching clinic that is attended by cardiology residents, congenital heart disease fellows, and maternal-fetal medicine fellows.

Women referred to the clinic have a range of cardiac conditions that are either acquired or congenital. Initial consultation is provided and the frequency of follow-up is determined by the severity of the underlying disease and the clinical status of the patient. Care provided through the clinic ranges from conservative follow-up and minimal intervention to more active management, which might include the following:

• Pharmacological treatment for complications such as heart failure, arrhythmias, pulmonary hypertension, and thromboembolism.
• Interventions such as electrical cardioversion, cardiac catheterization, ablation for arrhythmias, percutaneous closure of atrial septal defects, and mitral valvuloplasty.
• Cardiac surgery.

The integral role of obstetrics in this clinic ensures that both cardiac and obstetric care are provided in a planned and coordinated fashion. Many patients are referred from other parts of BC, and whenever possible support is given so that women with low or moderate risk can deliver in their community. The clinic has worked hard to organize patient-specific care plans regardless of the patient's risk level or place of deliv-
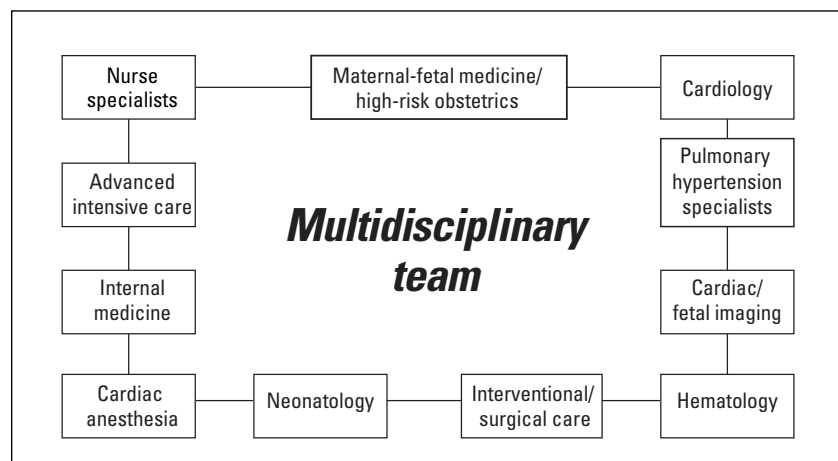


**Figure 1.** Services and specialists providing care to women at the Cardiac Obstetric (COB) clinic at St. Paul's Hospital.

ery. These highlight individual cardiac and/or obstetric concerns while helping to reassure and guide medical teams with patient management during pregnancy, labor, and delivery.

There is a monthly conference where the cases of all women followed through the clinic are discussed and care plans are reviewed by the members of the multidisciplinary COB team. A wide range of complex cardiac conditions have been successfully managed through the clinic. Patients have included those with cyanotic heart disease, single-ventricle physiology, severe pulmonary hypertension, and mechanical heart valve replacement. Many moderate-cardiac-risk and all high-cardiac-risk women are followed and deliver their babies at St. Paul's Hospital. The COB clinic also has a well-established registry and research is a very important component of the program.

### Preconception counseling

An additional essential service offered by the COB team is preconception counseling. It is imperative that couples understand the risk to maternal health posed by a pregnancy. Considerations include the risk of a cardiovascular complication in pregnancy, labor, or delivery; the long-term impact of pregnancy on the progression of underlying cardiac disease; and the possible effect of a cardiac lesion on maternal life expectancy. Understanding these risks allows couples to make informed choices about pursuing pregnancy. In some cases, women have been told previously that they should not become pregnant, when in fact this may not have been appropriate advice. In other cases, women with high-risk conditions such as pulmonary hypertension and cardiomyopathy may not be aware of all their risks and the care required

through a complex pregnancy.

Another important aspect of care for young women with CVD is related to their risk of bearing a child with congenital cardiac defects. The risk for parents without CVD is approximately 1%. The risk can be higher in parents with hereditary conditions, and in general the risk is higher when the mother rather than the father is affected by CVD.[8] Depending on the type of maternal heart disease, the recurrence risk in offspring varies between 3% and 50%.

## Pulmonary arterial hypertension

Pulmonary arterial hypertension is common in adult CHD, complicating around 10% of all cases.[9,10] PAH is a progressive condition resulting in hypertrophy and proliferation of the small pulmonary arteries, which can cause increased resistance to flow across the pulmonary circulation, right ventricular failure, and, ultimately, death.[11] While the condition is incurable, patients have benefited over the past 20 years from the development of remarkable therapies that slow the remodeling process and result in prolonged life and improved symptoms.[12,13]

In patients with congenital heart disease, PAH is triggered by systemic to pulmonary artery shunting. The increased blood flow through the pulmonary circulation induces the remodeling of the pulmonary vasculature that produces PAH.[14,15] Increased flow through the pulmonary arteries results in functional and structural changes to the small pulmonary arteries.[15-17] These changes increase the resistance to flow and result in a progressive increase in pulmonary artery pressures. Eventually, the pressures in the pulmonary circulation may rival those in the systemic circulation and reverse the direction of the shunt. The

consequent shunting of deoxygenated blood from the right side to the left side of the heart results in the chronic hypoxemia and cyanosis associated with Eisenmenger syndrome, the most advanced form of PAH associated with CHD.[18] This form of pulmonary hypertension represents a subtype of WHO group 1 pulmonary arterial hypertension.[19,20] Factors influencing its development include the complexity, location, and size of the CHD lesion[18,21] The most common presenting symptom is breathlessness.[16] Syncope is an ominous prognostic symptom that portends a poor outcome.[22]

### Screening for PAH

The screening test of choice for pulmonary arterial hypertension is a transthoracic echocardiogram. An estimated pulmonary systolic pressure greater than 35 mm Hg, especially if accompanied by right ventricular enlargement or dysfunction, should raise concern for PAH.[23] The diagnosis of PAH is based on invasive pressure measurement at cardiac catheterization. In PAH, catheterization reveals elevated pulmonary artery pressures (mean pulmonary artery pressure greater than 25 mm Hg) and low left atrial pressures (wedge pressure less than 15 mm Hg), along with elevated pulmonary vascular resistance (greater than 3 Wood units).[11] Given the rarity and complexity of PAH associated with CHD, it is essential that evaluation and management proceed in a centre with expertise in the management of both CHD and PAH.

### Therapy for PAH

Currently, agents for PAH approved for use in Canada include the prostanoid agonists (epoprostenol and treprostinil), endothelin receptor antagonists (bosentan, ambrisentan,

and macitentan), the phosphodiesterase type 5 inhibitors (sildenafil and tadalafil), and the soluble guanylate cyclase stimulator riociguat. These agents were approved primarily on the basis of trials done in the general WHO group 1 PAH population. However, there are a few notable exceptions where patients with PAH associated with CHD were studied specifically,[24-28] or are being studied specifically.[29] Unfortunately, research results so far show that therapy with these agents slows but does not halt or reverse pulmonary vascular remodeling. Many patients eventually worsen despite optimal pulmonary hypertension therapy. For these patients, either lung transplant, lung transplant with cardiac surgery to repair the congenital defect, or combined heart-lung transplant are ultimately required.

In British Columbia, care for patients with CHD-associated PAH is centralized at St. Paul's Hospital in Vancouver at the Pacific Adult Congenital Heart (PACH) clinic, the first such clinic in Canada and the model for other adult CHD centres. At the clinic, each patient is seen by both a pulmonary hypertension expert and an adult CHD cardiologist. This has been a highly successful collaborative venture that has resulted in markedly improved communication between health care providers and much more efficient and effective care for patients. Patients followed through this clinic are frequently on pulmonary arterial hypertension therapy, including endothelin receptor antagonists, phosphodiesterase type 5 inhibitors, or a combination of these agents. A strong partnership between the clinic and general cardiologists, respirologists, internists, and primary care physicians outside the Lower Mainland allows these patients to be followed in their local communities throughout the province.

## Arrhythmias

Arrhythmias are often the first manifestation of deterioration in complex CHD, and can lead to further cardiac decompensation if not treated on a priority basis. Arrhythmias in adult CHD should be identified, investigated, and treated promptly with input from an adult CHD centre. A thorough clinical history, physical examination, and hemodynamic assessment are essential. If any associated symptoms, heart failure, and/or hemodynamic abnormalities are identified, prompt referral to an adult CHD heart rhythm specialist is indicated.

Up to 30% of adult CHD patients have significant arrhythmia as an additional diagnosis. Arrhythmias are the leading cause of morbidity, impaired quality of life, emergency room visits, hospitalization, and mortality in this patient population.[30] The entire spectrum of arrhythmias is encountered in adult CHD, with several types often coexisting in the patient at presentation or afterwards. Several factors make the heart more susceptible to rhythm disorders in adult CHD, including congenitally displaced or malformed sinus nodes or atrioventricular conduction systems; primary myocardial disease; scarring from previous ischemic insult or surgery; residual or postoperative hemodynamic sequelae; and intra-atrial or intraventricular conduction propagation.

Certain adult CHD lesions are associated with a very high risk of rhythm problems. For example, in congenitally corrected transposition of the great arteries, approximately 20% of patients develop complete atrioventricular node conduction block by adulthood and require pacemaker implantation.[31] In patients with prior surgery in the region of the sinus node or its arterial supply (e.g., patients who have undergone a Mustard or Senning procedure for trans-

position of the great arteries), incidence of bradycardia with sinus node dysfunction is high.[32]

Approximately 50% of adults with CHD develop an atrial tachyarrhythmia during their lifetime.[33] Intra-atrial reentry tachycardia or flutter is the most common tachyarrhythmia in adult CHD due to scar-related abnormalities. Although atrial fibrillation is relatively uncommon in the younger adult CHD population, the prevalence of atrial fibrillation increases with age. It is important to note that atrial arrhythmias can often be difficult to detect in this population and the clinician needs to maintain a high index of suspicion as atrial arrhythmias can lead to catastrophic events. Ventricular arrhythmias are the leading causes of sudden death in several subtypes of CHD. Although the absolute incidence of cardiac arrest remains relatively low (approximately 0.1% per year), the overall risk is up to 100 times higher than in an age-matched control population.[34]

### Investigating arrhythmias

Accurate delineation of arrhythmias can be accomplished with 12-lead electrocardiogram, Holter monitoring, cardiac event loop recorders, implantable loop recorders, and interrogation of already implanted devices such as pacemakers or defibrillators. An electrophysiological study (EPS) may be considered when the conventional diagnostic workup is unrevealing in adults with CHD and symptoms suggest sustained arrhythmia. An EPS can also be indicated in cases with unexplained syncope and high-risk anatomical substrates associated with primary ventricular arrhythmias or poorly tolerated atrial tachyarrhythmias. High-risk substrates include tetralogy of Fallot, transposition of the great arteries with atrial switch surgery, and systemic or

single-ventricle anatomy. However, an inability to induce an arrhythmia in the electrophysiology lab does not fully exclude the possibility of a clinical arrhythmia.[35]

Many complications can occur as a result of arrhythmias, including heart failure, thromboembolism, and sudden cardiac death, and it is important to ensure that worsening hemodynamics are not the cause of the arrhythmia. Adults with CHD who have new-onset or worsening arrhythmias and those who have been resuscitated after sudden cardiac death should undergo hemodynamic assessment, including detailed imaging with echocardiography, cardiac magnetic resonance imaging, and/or cardiac catheterization. New or worsening regurgitant or obstructive lesions, shunts, ischemia, ventricular dysfunction, and coronary abnormalities can all precipitate arrhythmias.

### Managing arrhythmias

Managing arrhythmias in adult CHD patients can be complex and may involve additional considerations:

- Coexisting sinus or atrioventricular node dysfunction.
- Large scar formation and other effects of previous cardiac surgery.
- Underlying hemodynamic lesions.
- Vascular access issues.
- The patient's childbearing potential.

Such considerations can make input from an adult CHD arrhythmia specialist vital. For example, if pacemaker implantation is recommended for a patient with a heart that is difficult to access because of baffles and abnormal anatomy, endovascular rather than epicardial lead placement may have to be considered. Vascular access can also be an issue in a patient requiring electrophysiology studies and ablation therapy because pharmacological therapy is ineffective. Again, impenetrable scar tissue,
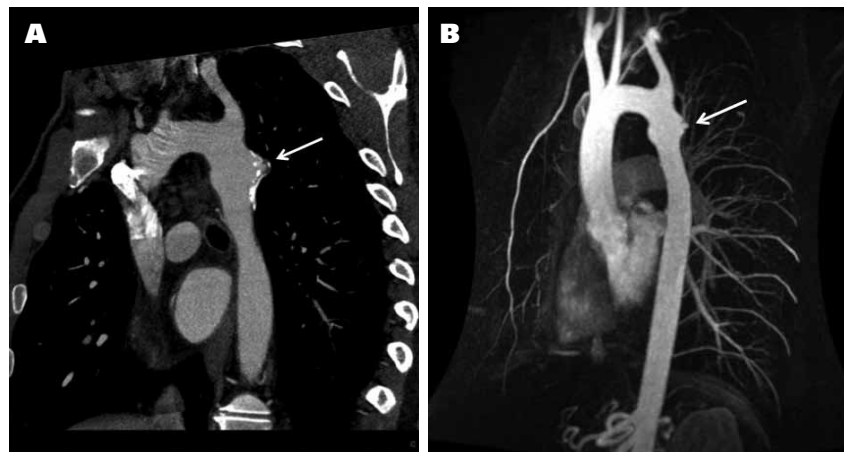


**Figure 2.** Complementary imaging techniques were used to reveal a small pseudoaneurysm (see arrows) at the site of a previous coarctation repair in the thoracic aorta of a 38-year-old male.

**A:** Multiplanar reformatted IV contrast-enhanced ECG-gated CT image. **B:** Sagittal oblique view of an MRI time-resolved imaging of contrast kinetics (TRICKS) sequence following administration of gadolinium.

baffles or conduits, and abnormal intracardiac connections may have to be taken into account.

Arrhythmia management should also include risk assessment for sudden cardiac death, heart failure, and thromboembolic risk—details beyond the scope of this article but readily available from the Heart Rhythm Society[30] and Canadian Cardiovascular Society.[36]

## Role of imaging in adult CHD

With advances in imaging technology and the longer life expectancy of CHD patients, the role of diagnostic imaging in this patient population has expanded. Echocardiography is the main routine imaging modality in adults with CHD, enabling assessment of ventricular function, valvular function, and integrity of surgical repairs. Magnetic resonance imaging (MRI), with its excellent spatial resolution and ability to assess ventricular and valvular function without the use of ionizing radiation, has played an essential role in the evaluation of

adult CHD. Concerns about potential stochastic effects of ionizing radiation have previously limited the use of multidetector computed tomography (MDCT). However, the introduction of radiation dose-reduction strategies and recent advancements in CT technology have made MDCT an essential tool for the evaluation of many patients with CHD. Recent advancements include submillimetre spatial resolution in all imaging planes, the ability to synchronize the acquisition to the ECG, and temporal resolution as low as 66 msec.

The imaging modalities now commonly used in adult CHD for diagnosis (**Figure 2**), assessment (**Figure 3**), and follow-up all have strengths and weaknesses.

MRI is the most common noninvasive imaging modality used to support echocardiography. It offers excellent three-dimensional assessment and visualization of the often complex postsurgical anatomy and highly reproducible quantification of left and right ventricular volumes and systolic function. It is also com-
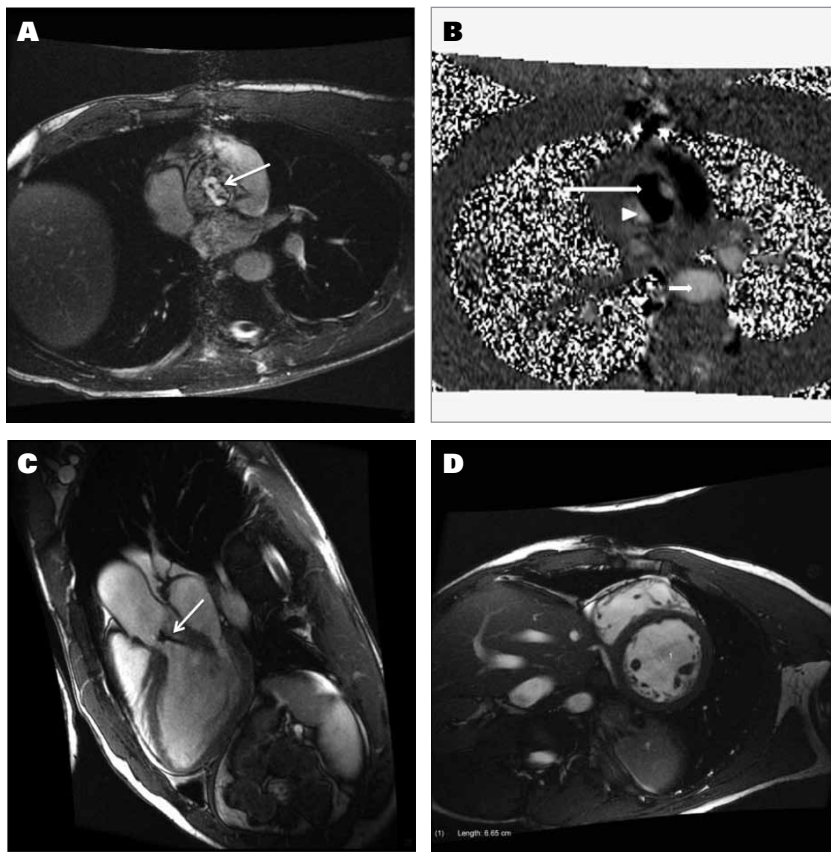
**Figure 3.** Several imaging modalities were used to assess a 27-year-old male for aortic dilatation, aortic regurgitation (AR), and left ventricular function and size in the setting of bicuspid aortic valve.

**A:** Bicuspid anatomy (arrow) seen with aortic valve plane FIESTA MRI sequence. **B:** Black forward flow (long arrow) with white regurgitant flow (arrow head) in same direction as white descending aortic flow (short arrow) seen with functional quantitative assessment of AR on phase contrast imaging. **C:** Qualitative visualization of AR by flow jet (arrow) across valve plane seen on FIESTA left ventricular outflow tract view. **D:** Ventricular functional analysis and size evaluation seen on short-axis FIESTA imaging.

monly used for the assessment of valvular function and for myocardial tissue characterization through the administration of intravenous gadolinium contrast medium.[37-40] Importantly, MRI does not require the use of ionizing radiation and is therefore a good tool for serial follow-up. Such serial follow-up is warranted after tetralogy of Fallot repair to assess for degree of pulmonary insufficiency as well as size and function of the right ventricle; after coarctation repair for

assessment of aortic size and repair site complication; for the quantification of ventricular volumes and function in patients with complex cardiac anatomy; and for evaluation of surgical repair integrity and aortic dimensions. MRI-derived endpoints can also be essential to management in these circumstances.

Many adult CHD patients cannot undergo MRI assessment because they suffer from claustrophobia, they have metallic coils in place that

may heavily degrade image quality, or they have an implanted cardiac device. Fortunately, rapid improvements in MDCT have helped fill this imaging gap. Given the good concordance between MDCT and MRI findings, multidetector computed tomography is being used increasingly for the quantification of right ventricular volumes and function in those patients unsuitable for MRI assessment. MDCT is able to evaluate the configuration and anatomical dimensions of the right ventricular outflow tract, which are major factors when determining whether a patient is suitable for percutaneous pulmonary valve replacement.

Coronary CT angiography (CCTA) is now well established as the gold standard for noninvasive detection and exclusion of coronary stenosis. CCTA is also being used increasingly for evaluation of the coronary arteries in patients with coronary anomalies, coronary fistulas, and Kawasaki disease, and after surgical repair for CHD requiring coronary artery manipulation.

When combined with findings from clinical and physiological assessment, information from these complementary imaging modalities plays a key role in diagnostic and treatment decision making. Obtaining images in more complex adult CHD cases requires a multidisciplinary team with specific expertise and knowledge. Often the images are reviewed with the entire team so that different perspectives and interpretations can be integrated and considered in a clinically meaningful way.

## Summary
Pregnancy-related cardiovascular disease, pulmonary arterial hypertension, and arrhythmias are complications that can affect adult CHD patients.

With improvements in the treatment of congenital heart disease, the number of women with CHD who reach childbearing age is increasing. In BC a special multidisciplinary Cardiac Obstetrics clinic at St. Paul's Hospital provides coordinated care for pregnant women with cardiac conditions. In addition, the clinic offers preconception counseling so that couples can make informed choices about pregnancy.

The Pacific Adult Congenital Heart clinic, also based at St. Paul's, helps manage patients with pulmonary arterial hypertension, a progressive condition affecting around 10% of adult CHD patients. Patients followed through this clinic are frequently on PAH therapy, including endothelin receptor antagonists, phosphodiesterase type 5 inhibitors, or a combination of these agents.

Other adult CHD patients requiring follow-up are those with a significant arrhythmia, often the first manifestation of deterioration in complex CHD. Complications that can result from arrhythmias include heart failure, thromboembolism, and sudden cardiac death.

Adult CHD patients with any of the complications discussed here can benefit from recent advances in imaging technology. A range of complementary modalities now enable assessment of ventricular and valvular function (echocardiography and magnetic resonance imaging), quantification of right ventricular volume (multidetector computed tomography), and exclusion of coronary stenosis (coronary CT angiography).

## Competing interests

None declared for Drs Grewal, Brunner, Ellis, Leipsic, Levy, Barlow, and Chakrabarti. Dr Swiston has received honoraria for speaking engagements and advisory board participation from pharmaceutical companies that

> **Adult CHD patients with any of the complications discussed here can benefit from recent advances in imaging technology.**

market products used to treat pulmonary arterial hypertension: Actelion, Eli Lilly, Pfizer/Encysive, Bayer, GSK, and Unither.

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