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Part I: Rationale and Utility. An Expert Consensus Document of the Society of
Cardiovascular Computed Tomography (SCCT)

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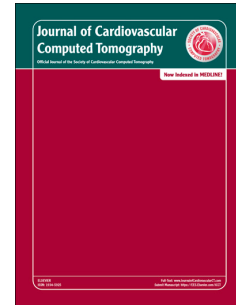
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Computed Tomography Imaging in Patients with Congenital Heart Disease, Part I: Rationale and Utility. An Expert Consensus Document of the Society of Cardiovascular Computed Tomography (SCCT)

Endorsed by the Society of Pediatric Radiology (SPR) and the North American Society of Cardiac Imaging (NASCI)

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PREAMBLE:

This is an expert consensus document created to provide information about the current use of cardiovascular computed tomography (CT) in patients of all ages with proven or suspected congenital heart disease (CHD). The discussion and recommendations are based on available literature and the judgment of a diverse group of subspecialists with extensive experience in the use of CT imaging in CHD. The field of CHD CT imaging is evolving rapidly with the availability of new scanner technology. In addition, the prevalence of palliated CHD has increased with marked improvements in patient survival. We believe it is important to review the clinical indications, strengths, limitations, and risks of cardiovascular CT in this patient population. This is the first of two complementary documents. It will concentrate on the disease entities and circumstances in which CT may be used. The second document will focus on recommendations for the technical performance of cardiovascular CT in patients with CHD.

Successful cardiovascular CT imaging of CHD requires an in depth understanding of the core teaching elements of both cardiology and radiology. The ability to perform and interpret high quality congenital cardiovascular CT in a clinical

context requires focused time and effort regardless of the previous background of the cardiac imager. This is reflected by a writing committee that consists of pediatric and adult radiologists and cardiologists, all whom have extensive experience in performing CT in this patient population. Cardiovascular CT is complementary to other imaging modalities and its optimal use will be in centers where all diagnostic modalities are available. The choice of modality for an individual patient should be determined by age, diagnosis, clinical condition, clinical question and patient preference.¹⁻⁴ Use of CT in CHD should be reserved for situations in which it is expected to provide unique diagnostic information for the individual patient or clinical indication, and/or less risk than other modalities. This multi-disciplinary document is intended to guide the optimal selection of CHD patients for cardiovascular CT.

The goals of this document apply to both pediatric and adult CHD patients and are to:

- 1) Review the current use of cardiovascular CT
- 2) Assess the most up to date information on risks, benefits, as well as limitations of cardiovascular CT
- 3) Provide disease-specific indications for cardiovascular CT imaging
- 4) Outline a consensus opinion on the essential skills and knowledge needed to optimally perform and interpret cardiovascular CT

INTRODUCTION: Why CT is increasingly used in CHD

Changing CT Technology:

The first clinical CT scanners had limited use for cardiac applications due to poor spatial and temporal resolution, and long scan times. There has been a marked improvement in CT scanner technology in the past decade. Current generation multidetector CT (MDCT) scanners allow rapid coverage of large anatomic volumes, submillimeter isotropic spatial resolution and temporal resolution as low as 66 msec. These advances provide diagnostic images of small cardiovascular structures, even at the high heart rates encountered in a pediatric population.⁵⁻¹³ Data acquisition now requires only a portion of the cardiac cycle or at most several cardiac cycles. The highest pitch scan modes and volumetric scanners provide full anatomic coverage of a pediatric thorax in less than a second or a single heartbeat, freezing respiratory motion. This rapid image acquisition eliminates or reduces the need for sedation and anesthesia in those unable to cooperate with a short breath hold.^{10, 14} The prospective delivery of radiation to a limited portion of the cardiac cycle and post processing approaches such as iterative reconstruction allow for significantly reduced radiation doses while maintaining or improving image quality.¹⁵⁻¹⁷

The use of cardiovascular CT has been described in patients of all ages with cardiac malformations of all levels of complexity. Detailed coronary artery imaging is possible in nearly every patient using a current generation CT scanner. Retrospectively ECG gated scans may be performed for quantification of ventricular function with an accuracy that is equal to cardiovascular magnetic resonance (CMR), the modality most often used as the reference standard.¹⁸ Non-cardiovascular anatomy, including airway,

lung parenchyma, and skeletal anatomy is clearly seen. Cardiovascular CT also provides excellent visualization of stents, conduits, and metallic objects and can be performed in patients with implanted pacemakers and defibrillators.¹⁹

Limitations of cardiovascular CT include poor myocardial tissue characterization, inability to quantify valve regurgitation in patients with more than one regurgitant lesion or shunt, and exposure to ionizing radiation. Additionally, intravenous administration of iodinated contrast with its attendant risks is required in almost all patients for vascular opacification. Although breath holding is no longer required for many indications on high pitch and volumetric scanners, it is still needed for images acquired over several heart beats, including functional imaging and detailed coronary artery imaging at high heart rates. For this reason anesthesia is still required for specific indications in young or critically ill patients who are unable to cooperate with breath holding.

Advanced diagnostics in the current era are primarily non-invasive, and cardiovascular CT is increasingly used as an adjunct to echocardiography when CMR is considered high risk, contraindicated, or unlikely to provide images suitable-quality to answer the clinical question.^{20,21}

Changing Patient Population and Diagnostic Paradigm:

Congenital heart disease is the most common congenital anomaly. Survival after surgical intervention for all forms of CHD is now expected for most patients.²²⁻²⁵ The Society of Thoracic Surgeons database reports a national overall mortality for all CHD operations of 3.5% for 2010-2013.²⁶ The average age of patients with CHD is

continually increasing and has reached adulthood. In fact, 2/3 of patients with CHD are now adults, and the number of those reaching ≥ 60 years of age is increasing rapidly.^{24, 27-29} Much of the cardiac morbidity occurs in older patients; and mortality in CHD has shifted from infants towards adults.^{22, 29-31} These complex patients often have residual hemodynamic lesions requiring repeat intervention throughout life, and therefore, require close surveillance and have high utilization of health care resources.^{32,33}

It is widely recognized that catheterization is no longer required for the diagnosis and management of most forms of CHD. It is now reserved for patients needing invasive hemodynamic evaluation or catheter based intervention.³⁴ Non-invasive imaging can establish the details of anatomy with the degree of certainty required for surgical intervention for most CHD indications.³⁵⁻³⁸ The availability of cardiovascular CT and CMR that is supervised, performed, and interpreted by physicians with expertise and training in congenital heart disease has become an essential component of regional pediatric and adult CHD centers.²³

Echocardiography remains the standard initial imaging modality in CHD, and has excellent diagnostic accuracy when performed by skilled practitioners.^{20, 35} Echocardiography routinely visualizes intracardiac anatomy, and is both portable and widely available. A significant limitation of echocardiography is its poor reproducibility in quantifying single or right ventricular size and systolic function and valve regurgitation.^{39,}⁴⁰ Echocardiography is often unable to adequately assess distal pulmonary arteries, complex systemic or pulmonary venous anatomy, and cavo-pulmonary anastomoses in patients with single ventricle physiology.^{39, 40} Given the reliance on transmission and

receipt of ultrasound energy through the chest, echocardiographic images may be inadequate due to limitations of the “acoustic window” in patients with large and small body habitus, or those with scoliosis, metallic implants, or other alterations in the chest wall.

CMR is the modality most often used as an adjunct to echocardiography for CHD when further information is needed.^{20, 21, 41} It is excellent for 3D visualization of complex anatomy, reproducible quantification of single and right ventricular function, quantification of valve regurgitation, myocardial tissue characterization and stress imaging.⁴²⁻⁴⁶ CMR is considered the standard for quantification of ventricular size, systolic function and valve regurgitation to which other modalities are compared. CMR uses no ionizing radiation, and gadolinium-based contrast is needed for angiography only where the non-contrast 3D sequences are inadequate. In institutions with access to both cardiovascular CT and CMR, CMR is used more commonly due to the favorable risk profile and excellent diagnostic quality for most indications and patients.²⁰

Although advances such as real-time cine imaging,⁴⁷ single heartbeat delayed enhancement imaging⁴⁸ and highly accelerated parallel imaging⁴⁹ allow completion of even the most complex CHD patients within 1 hour, CMR still usually requires relatively long imaging times.^{50, 51} Children younger than eight years of age, and developmentally delayed patients of all ages require sedation or anesthesia for the MR study. Intravenous (IV) gadolinium contrast is needed only for certain indications. Due to the risk of nephrogenic systemic fibrosis, its use is contraindicated in patients with acute or

chronic severe renal (kidney) disease defined as glomerular filtration rate < 30 mL/min/m²; or renal dysfunction due to the hepato-renal syndrome.⁵²⁻⁵⁴

Many patients with CHD require placement of metallic devices such as coils and stents that may degrade CMR image quality due to susceptibility artifact. The combination of an endovascular coil and a stent has been shown to decrease the diagnostic utility of CMR in Fontan patients to <10%.⁵⁵ Pacemaker and defibrillator use is common in patients with CHD.^{19, 56-58} While MRI safe pacemakers are now available and some non-pacemaker dependent patients with older devices may undergo MRI,^{59, 60} imaging artifact from the device may continue to obscure anatomy, such as epicardial devices with leads directly adjacent to the heart.⁶¹

SYSTEMATIC REVIEW OF THE USE OF CT IN CHD

CT has been used to assess complex CHD for over two decades. There are many excellent comprehensive review articles on the use of cardiovascular CT for the pre- and postoperative evaluation of patients of all ages with congenital cardiovascular disease.^{1, 3, 5, 7, 62-73} Cardiovascular CT has been used for detection and follow-up of extracardiac vascular lesions, intracardiac lesions, and pericardial diseases.^{2-4, 7, 16, 69, 74-89} The next section provides a lesion-specific review of the use of CT for the most commonly referred CHD diagnoses.

Coronary Imaging

Coronary CTA is well established in adult patients for coronary artery imaging.⁹⁰⁻⁹³ The Society of Cardiovascular Computed Tomography has established guidelines for both the acquisition and reporting in coronary artery CT for atherosclerotic heart disease in adults.^{94, 95} Increasing evidence supports coronary CT for evaluation of the coronary arteries in patients with pediatric and congenital cardiovascular disease, including congenital coronary anomalies, coronary fistula, Kawasaki disease, and after CHD surgical repair requiring coronary artery manipulation.⁹⁶⁻¹⁰⁹

Use of CT for congenital coronary artery anomalies

Congenital coronary anomalies are the second most common cause of sudden death in young athletes^{110, 111} and are present in 0.2-2% of the population.^{112, 113}

Echocardiography can accurately diagnose coronary anomalies in children when performed by a skilled echocardiographer, but it is limited in its ability to fully characterize coronary anatomy in many adult patients and is prone to false negatives.¹¹⁴⁻¹¹⁷ Coronary artery dominance, angulation from the aortic root, ostial narrowing and presence and length of intramural course cannot be reliably determined by echocardiography. These anatomic features are considered by some to be linked to prognosis. Precise anatomic definition with advanced imaging aids in surgical planning when indicated.¹¹⁸⁻¹²⁰ Coronary CTA in patients of all ages with coronary anomalies is well described and has superior accuracy for this indication because of the ability to simultaneously visualize the coronary arteries as well as the great vessels.^{117, 119, 121-127} CMR has been shown to be useful for congenital coronary anomalies in older children and adolescents, but is less useful in the youngest patients because image quality is

inversely related to both patient age and heart rate.^{128, 129} Also, CMR is often unreliable in the evaluation of the distal coronary artery anatomy to determine coronary dominance in young patients.^{128, 129} Coronary anomalies are common in patients with CHD, and precise anatomic definition prior to surgical intervention is often indicated since it may alter the surgical course.¹³⁰ Current guidelines recommend that all patients that have previously undergone surgical coronary artery manipulation have complete angiographic assessment at least once in adulthood, and that intervention on the RVOT should be preceded by unambiguous definition of coronary artery anatomy.²³ The modality chosen for coronary assessment will depend on the age of the patient and institutional capabilities. See lesion-specific sections below for additional detail (TOF, transposition complexes).

Use of Coronary CTA for Acquired Coronary Artery Disease in Pediatric and CHD Patients:

As long term survival in CHD continues to improve, patients may acquire coronary artery disease that can affect outcome for congenital surgeries performed in adulthood, and concomitant CABG may be required.^{27,131} Cardiac CTA is useful for simultaneous evaluation of congenital anatomy and of coronary arterial pathology in adult patients with symptoms that may be attributable to coronary artery disease. High risk CHD patients undergoing cardiac intervention should have preoperative evaluation of the coronary arteries.²³

Kawasaki disease (KD) is the most common acquired cardiac disease in children in the United States. Despite adequate treatment, 3-5% percent of patients develop coronary artery aneurysms or ectasia.¹³² While aneurysms in these patients are frequently identified in the proximal coronary arteries on transthoracic echocardiography by a skilled pediatric echocardiographer, commonly-occurring mid and distal coronary artery aneurysms and coronary stenoses are poorly visualized.⁹⁸⁻¹⁰⁴ In long-term follow-up, patients with a history of KD and aneurysms may develop coronary stenoses, occlusions, calcifications, thrombi and embolic infarction.¹³² Coronary CTA offers comparable accuracy to conventional coronary angiography^{105, 106} which has historically been considered the reference standard for evaluation of coronary aneurysms and stenoses in patients with KD. Recent reports of both calcification and plaque identification by coronary CTA in high risk patients with a history of KD may identify a subset of patients at higher risk of future adverse event.¹⁰⁷ CMR is described for definition of coronary aneurysm, but is less sensitive than coronary CTA for identification of stenoses, calcifications, ectasia, and distal coronary artery disease.^{105, 108, 109}

Thoracic Vasculature Abnormalities (Pulmonary/systemic venous abnormalities, aortic/pulmonary arterial anomalies and vascular rings/slings):

Cardiovascular CT evaluation of pulmonary venous anomalies is well described and has been shown to be highly specific when compared to operative findings.¹³³⁻¹³⁶

Cardiovascular CT is accurate for determining the site of anatomic obstruction in anomalous pulmonary venous return and for the diagnosis of pulmonary vein stenosis.¹³⁷⁻¹⁴² Systemic venous anomalies are also well visualized by cardiovascular CT.¹⁴³⁻¹⁴⁵

Cardiovascular CT has also been shown to accurately visualize congenital aortic anomalies including interrupted aortic arch and aortic coarctation in both pediatric and adult patients.¹⁴⁶⁻¹⁵³ It is particularly useful for evaluation of the aortic arch after endovascular intervention (stent or stent graft) where aneurysm, aortic wall injury or recurrent arch obstruction are relatively common.¹⁵⁴⁻¹⁵⁹ It is recommended that every patient with repaired or unrepaired aortic coarctation have comprehensive evaluation of the thoracic aorta, and that those who have undergone intervention should undergo serial evaluation by cardiovascular CT or CMR throughout adulthood.²³

Cardiovascular CT may be considered the optimal diagnostic modality for evaluation of suspected vascular rings and slings, and for assessment of vascular anatomy and associated tracheobronchial narrowing. The ability of cardiovascular CT to simultaneously image vascular structures and airway structures makes it an ideal imaging modality prior to surgical intervention. In addition to detailing the precise anatomy and measurements, cardiovascular CT allows the imager to describe and quantify involvement of the trachea and bronchi including assessment for complete cartilaginous rings. Multiple groups have shown that cardiovascular CT accurately characterizes tracheomalacia and vascular anatomy resulting in airway compression pre- and postoperatively in patients with symptomatic thoracic vascular anomalies.^{147,}

^{148, 160-168} In symptomatic patients seeking surgical relief, CT facilitates planning of the surgical approach and helps determine whether tracheal reconstruction or aortopexy will be necessary as well.¹⁶⁹

Cardiovascular CT is well established in the evaluation of pulmonary artery anomalies. Ductal continuation of the pulmonary artery with subsequent ductal closure and pulmonary artery isolation is optimally imaged with CT since the lung parenchyma and associated anomalies can be evaluated.¹⁷⁰ This lesion can be asymptomatic into adulthood.¹⁷¹⁻¹⁷⁴ Abnormal arterial supply to the lung segments such as seen in scimitar syndrome with sequestration is also well seen by cardiovascular CT.¹⁷⁵⁻¹⁷⁸

Cardiovascular CT is the imaging modality of choice to determine anatomic substrate and interventional planning for complex lung lesions such as intralobar or extralobar pulmonary sequestration.^{179, 180} In a study evaluating the utility of cardiovascular CT for surgical planning in these patients, treatments were correctly planned using cardiovascular CT with 100% accuracy, sensitivity and specificity.¹⁸¹

Septal Defects, Including ASD/VSD/AVSD:

Advanced imaging is rarely needed to evaluate atrial or ventricular septal defects unless associated with systemic or pulmonary venous anomalies. Cardiac CT may be considered prior to device placement in patients with large atrial septal defects (ASD) who have poorly visualized inferior-posterior rims on echocardiography.¹⁸² The retroaortic course of an anomalous circumflex coronary artery from the right facing sinus

can be identified prior to device placement additionally. CT evaluation of atrial and venous anatomy in symptomatic patients after Amplatzer device occlusion of ASD has been reported.¹⁸³ The region of patch closure of a septal defect may become calcified with aging. Since these lesions are the most common congenital cardiac abnormalities, previously unrecognized septal defects may be first identified by cardiac CT in patients undergoing scanning for other indications.¹⁸⁴ Relief of left ventricular outflow tract obstruction and AV valve revision or replacement are the most common re-interventions after repair of atrioventricular septal defects (AVSD).¹⁸⁵⁻¹⁸⁸ Cardiac CT may be useful in these patients when echocardiography is not fully diagnostic, although literature regarding cardiovascular CT specific to this diagnosis is not reported.

Tetralogy of Fallot (TOF with pulmonary stenosis or pulmonary atresia):

The anatomic targets assessed with cardiovascular CT in patients with tetralogy of Fallot (TOF) include main pulmonary arteries and pulmonary conduits, branch pulmonary arteries, aorto-pulmonary collaterals, postoperative shunts, coronary arteries, and the aortic root.¹⁸⁹⁻¹⁹⁶ Multimodality imaging is often needed for complete assessment and serial evaluation in these patients. MRI is considered by many experts to be the modality of choice for investigation after TOF repair unless detailed coronary imaging is needed.¹⁹⁷

The ability to reliably visualize pulmonary arterial supply makes cardiovascular CT an excellent imaging modality in patients with TOF who are not adequately imaged

by echocardiography prior to repair, particularly in those with pulmonary atresia.

Pulmonary blood flow in patients with TOF with pulmonary atresia (TOF-PA) may be supplied via a patent ductus arteriosus, aorto-pulmonary collaterals or both. In comparison to conventional angiography, cardiovascular CT has excellent accuracy in defining aorto-pulmonary collaterals in these patients prior to surgical unifocalization.^{195, 198, 199} On the other end of the spectrum, TOF with absent pulmonary valve, which is the least common form of tetralogy, often has severe pulmonary artery dilation. This dilation may cause bronchial compression, which is well visualized by cardiovascular CT as is any associated air trapping.¹⁶⁴

After complete repair of TOF, patients with residual pulmonary regurgitation often develop right ventricular dilation and dysfunction. Furthermore, during adulthood 20% of patients with repaired TOF develop left ventricular systolic dysfunction which may improve after pulmonary valve replacement.²⁰⁰⁻²⁰² Right and left ventricular size, systolic function and pulmonary regurgitant fraction are routinely evaluated in order to determine the optimal timing and type (surgical or catheter based) of pulmonary valve or conduit replacement.²⁰³⁻²⁰⁵ Adult patients with repaired TOF are at increased risk of sudden death after the second decade of life and many eventually meet criteria for placement of a defibrillator, making CMR a relative contraindication.²⁰⁶⁻²⁰⁸ For these select patients who are contraindicated for CMR, cardiovascular CT assessment of ejection fraction and ventricular volumes provides comparable information.²⁰⁹⁻²¹² In the absence of shunts or other significant valve disease, pulmonary regurgitation can be estimated from differences between right and left ventricular stroke volumes. Stroke volume

differences to estimate pulmonary regurgitation has been reported with adequate correlation to 3Tesla MRI in this patient subset.²¹³ Careful correlation to echocardiography should be used when interpreting stroke volume differences to determine valvular regurgitation since flow sequences cannot be used to verify findings as in MRI. If both tricuspid regurgitation and pulmonary insufficiency are present, the total stroke volume can be reported but not the severity of each lesion.

Methods for trans-catheter pulmonary valve placement have been developed for those who meet criteria for intervention. These valves have been primarily used in previously placed conduits with a diameter of 16 mm or larger. Recently they have been placed in the native right ventricular outflow tract (RVOT) and in smaller patients.²¹⁴⁻²¹⁶ Precise anatomic definition is required for optimal valve sizing and successful valve placement.

Congenital coronary anomalies are relatively common in patients with TOF, and it is important to define the coronary anatomy prior to surgery; particularly in patients with an anomalous coronary that crosses the RVOT.²¹⁷ A preoperative study in 100 patients under one year of age with TOF demonstrated that cardiovascular CT provided 100% sensitivity and specificity for coronary artery anatomy compared to surgical findings, with a radiation dose less than 1 mSv.¹⁸⁹ Coronary artery anatomy must be clearly defined prior to repeat intervention on the RVOT.²³ This is essential in patients undergoing repeat sternotomy with a substernal coronary artery, and also for those being considered for transcatheter pulmonary valve placement due to potential for coronary artery compression with device placement.²¹⁸⁻²²⁰ It is important to recognize

that the aortic root is commonly dilated in patients with TOF, measuring ≥ 40 mm in 28.9% of patients in a recent multi-institutional study.²²¹ Aortic root dimensions should be measured and reported in all TOF patients whenever a cardiovascular CT is performed.

Transposition Complexes:

Atrial Switch (Mustard or Senning Procedure):

The atrial switch was the procedure of choice for *d*-transposition of the great arteries (*d*-TGA) prior to development of the successful coronary artery reimplantation techniques that facilitate the arterial switch operation. Most patients who have undergone the atrial switch are young- to middle-aged adults. In these patients, systemic right ventricular (RV) failure and tricuspid regurgitation are common and are the primary predictors of mortality. For this reason, measurement of systemic RV function is critical, and recent guidelines are based on quantitative evaluation of ejection fraction.^{222,223} The pacemaker insertion rate is relatively high in this patient population, with a minority of patients in sinus rhythm 20 years after intervention.^{224,225} Complete, pre-procedural assessment of systemic venous anatomy to facilitate potential placement of stents or devices is recommended. In a single-center catheterization study, over 50% of patients had baffle complications; and pre procedural echocardiograms had a positive predictive value of only 37% compared to catheterization findings, underscoring the need for improved pre-procedural diagnostics.²²⁶ In a large cohort of adult patients who had undergone atrial baffle creation, systemic venous baffle obstruction rate was

significantly higher for patients who had undergone a Mustard vs Senning operation (risk ratio 3.5).^{227, 228} Cardiovascular CT is able to visualize systemic and pulmonary venous baffles and identify baffle obstruction, evaluate RV size and function, and estimate tricuspid regurgitation using stroke volume differences from functional analysis.^{209,229-232} If stroke volume differences are used for estimation of regurgitant fraction, findings must be correlated with echocardiographic Doppler evaluation. Baffle leaks are difficult to reliably visualize using cardiovascular CT unless there is differential opacification showing a negative or positive contrast jet between the atria. This is problematic when a biventricular contrast injection protocol is used and there is similar contrast density in both atria. Cardiovascular CT has been described for follow-up evaluation of both baffle stents and EP device placement.²³¹ Another potential indication for cardiovascular CT in this population includes pacemaker dependent patients who are referred for cardiac resynchronization therapy. Pre-procedural evaluation of coronary sinus and coronary venous anatomy by cardiovascular CT can help determine the procedural approach for EP device lead placement.^{233,234}

Arterial Switch:

The arterial switch operation (ASO) for *d*-TGA was first described by Jatene in 1975, and has been widely applied since the 1980s.²³⁵ The first patients to undergo arterial switch are now young adults. With *d*-TGA, abnormalities of coronary origin and course are common and impact immediate and long-term surgical outcomes.²³⁶ Overall, survival after an ASO is excellent. Nevertheless, late deaths resulting from coronary ischemia and arrhythmias have been documented, and the rate of reintervention is

relatively high.²³⁷⁻²³⁹ Major complications that may occur after the arterial switch operation include coronary ostial stenosis, neo-pulmonary artery and branch pulmonary artery stenosis, and neo-aortic root stenosis, dilatation or insufficiency. The most common indication for intervention is for relief of supra-valvar pulmonary stenosis.²⁴⁰ As noted above, cardiovascular CT performs well for visualization of the all aspects of the right ventricular outflow tract, and branch pulmonary arteries.

Since myocardial perfusion via reimplanted coronary arteries is the primary determinant of mortality and long-term outcomes in these patients, imaging of the coronary anastomoses is recommended in symptomatic patients, as well as at least once during adolescence or early adulthood in asymptomatic patients.^{23, 241, 242} A recent cardiovascular CT evaluation of 190 patients 5-16 years of age found 8.9% of patients with coronary lesions (defined as > 30% narrowing to occlusion) confirmed by invasive angiography.²⁴³ Other studies have shown similar rates of coronary compromise, primarily in asymptomatic children.^{241,244,245} Cardiovascular CT has been shown to be highly accurate in evaluating coronary arteries before and after an ASO.^{130,245,246} No accepted standard for routine interval coronary evaluation exists. Cardiovascular CT evaluation of coronary artery stenosis after the ASO has been shown to correlate well with invasive angiography, and is preferred since catheter placement may alter the coronary ostium. CT also provides information on the underlying mechanism of coronary luminal narrowing.²⁴⁵ Evaluation after bypass grafting for coronary stenosis resulting from an ASO in children using cardiovascular CT has been reported as well.^{247,}

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Complex Transposition Repair (Rastelli and Nikaidoh):

In some patients with complex transposition, such as those with *d*-TGA with a VSD and left ventricular outflow tract obstruction or certain patients with double outlet right ventricle, an ASO is not feasible. The Rastelli procedure is the most common surgical intervention in this situation. This includes closure of the VSD using a patch from the crest of the ventricular septum to the distant aorta and placement of a right ventricle to pulmonary artery conduit. As with all other forms of surgery requiring placement of a conduit, there is potential for stenosis or insufficiency of the conduit, and the relationship of the coronary arteries should be evaluated prior to repeat intervention. A multi-institutional study performed in 2010 revealed a survival of 58%, and an event free survival of 26%, at 20 years after a Rastelli procedure.²⁴⁹ There is a relatively high re-intervention rate for both right and left ventricular outflow tract obstruction, and a majority of patients will require pulmonary conduit replacement.²⁴⁹⁻²⁵¹ The pathway between the left ventricle and aorta may become obstructed, and determining the anatomic substrate is crucial to determine the method of intervention, when indicated. The Nikaidoh procedure, which has gained popularity in recent years, is a procedure in which the aorta is translocated closer to the VSD. Since the aorta must be moved leftwards towards the VSD, right coronary artery lesions are a potential complication.²⁵²⁻
²⁵⁴ All of the anatomic lesions seen after the Rastelli and Nikaidoh procedures can be readily assessed with cardiovascular CT, although literature for this indication is limited to descriptive case reports.²³²

Congenitally Corrected Transposition:

Patients with congenitally corrected transposition (also known as *I*-TGA) have a high rate of complete heart block requiring pacemaker placement. The most simple form (with no associated intra-cardiac defect) may be first uncovered as an incidental finding in CT performed for another indication.^{255, 256} Cardiovascular CT can be used to assess atrial, ventricular and arterial relationships and to evaluate systemic right ventricular function.²⁵⁷⁻²⁵⁹

Some patients with *I*-TGA can be managed without surgery, and those that undergo surgery may either have a “physiologic” or “anatomic” repair. The “physiologic repair” keeps the right ventricle as the systemic ventricle, occasionally with a left ventricle to pulmonary artery conduit, while an “anatomic repair” consists of an atrial switch plus an arterial switch or Rastelli procedure. Both surgical options have similar medium term outcomes, except for those with significant tricuspid regurgitation, which is better tolerated in an anatomic repair with a systemic left ventricle.²⁶⁰ Complications, follow-up, and cardiovascular CT imaging are similar to what is described above based on type of repair (atrial switch, arterial switch, Rastelli).

Single Ventricle Heart Disease:

Patients with a functionally single ventricle, including those with tricuspid atresia, pulmonary atresia, hypoplastic left heart syndrome, double inlet left ventricle, and unbalanced atrioventricular septal defects, generally follow a palliative surgical pathway with 2-3 stages. The first stage, if necessary and dependent on the physiology, is

performed as a neonate and usually involves a Norwood procedure or systemic to pulmonary arterial shunt. Some centers advocate a “hybrid” approach utilizing a catheter-placed ductal stent and pulmonary artery bands. The most common systemic to pulmonary arterial shunt is the Blalock-Taussig shunt, but right ventricle to pulmonary artery shunts (Sano shunt) and central shunts (from ascending aorta) are other common types. At 4-6 months of age the shunt is taken down and the superior vena cava is anastomosed to the pulmonary artery (Glenn or Hemi-Fontan procedure). With the third stage (Fontan completion) the inferior vena caval flow is directed into the pulmonary arteries. In the current era, the third stage palliation is typically performed between 18 months and three years of age. Clinical outcome is dependent upon the morphology of the single ventricle and patients with a systemic left ventricle do better during second stage palliation, have improved ejection fraction, lower rates of valvular regurgitation and fewer long term complications.²⁶¹⁻²⁶³ Although patients with a systemic right ventricle do not do as well, it is now expected that 70% will survive to adulthood and most patients do well clinically.^{264, 265} A single institution reported a median radiation exposure of 25.7 mSv through the Fontan operation using primarily catheter based diagnostics.²⁶⁶

Prior to stage 1 surgery

While many patients with single ventricle anatomy can be imaged adequately using echocardiography prior to stage 1 surgery, cardiovascular CT is occasionally necessary to define complex systemic or pulmonary venous, aortic, or pulmonary artery anatomy, particularly in patients with atrial isomerism. Given that pulmonary venous anomalies

are a significant risk factor for survival in these patients, it is critical that the pulmonary venous anatomy is defined accurately prior to intervention.²⁶⁷⁻²⁶⁹ Cardiovascular CT is excellent for this application, and can be performed with minimal or no sedation in most cases. (See section above on thoracic vascular abnormalities).

After stage 1 surgery (Norwood, systemic to pulmonary arterial shunt, hybrid)

Between stage 1 and 2 surgery, systemic and pulmonary artery stenoses are relatively common, and are often insufficiently visualized with echocardiography.³⁹ Patients with systemic to pulmonary artery shunts occasionally experience shunt thrombosis, resulting in acute, profound cyanosis. Shunt thrombosis can be challenging to identify with echocardiography, but cardiovascular CT, given its easy accessibility and short imaging time, is an excellent imaging modality to identify this problem and identify when intervention is necessary.^{270, 271}

In most centers, cardiac catheterization is performed in preparation for a stage 2 procedure. A recent comparison of cardiovascular CT and catheterization prior to stage 2 palliation revealed excellent correlation to surgical findings for both modalities and no difference in surgical outcome to hospital discharge.²⁷² The estimated cardiovascular CT radiation dose (both age and size adjusted) was 1 mSv compared to a catheterization dose estimate of 14 mSv. Additionally, the catheterization group had higher contrast dose, required central vascular access and general anesthesia in all cases, and had a relatively high rate of adverse events. A prior study randomized pre-stage 2 patients to CMR or catheterization, and found no difference in surgical

outcomes or medium term outcomes for patients followed a median of 8 years.²⁷³ Some centers now propose a completely non-invasive diagnostic pathway for patients with single ventricle heart disease through third stage palliation.^{274, 275} The single ventricle patient population is high risk for adverse event with anesthesia.²⁷⁶⁻²⁷⁸ For single ventricle patients that may require anesthesia for CMR, cardiovascular CT may be a reasonable alternate imaging modality if performed with no or minimal sedation.

After Stage 2 surgery (Glenn or Hemi-Fontan procedure) or Stage 3 surgery (Fontan)

Cardiovascular CT has been shown to adequately visualize all aspects of the Glenn or Fontan circuit after single ventricle palliation.²⁷⁹⁻²⁸⁶ Thrombus formation after the Fontan procedure is relatively common, and thrombi have been visualized by cardiovascular CT in the Fontan conduit, residual ventricle or in the residual PA stump after pulmonary artery ligation.²⁸⁷⁻²⁹⁰ Pulmonary embolism has also been identified by cardiovascular CT.²⁹¹ Care must be taken, however, to optimize the contrast injection technique both to avoid a false positive diagnosis of pulmonary embolism and to optimally opacify the Fontan circuit.^{232, 285, 292} Unopacified venous blood from the hepatics mixing with a lower extremity injection, or inferior vena cava mixing with contrast from an upper extremity injection can be mistaken as clot or embolism. As with TOF or TGA, quantification of ventricular function by cardiovascular CT may be warranted in patients with metallic implants and contraindications to CMR.

After Ross Procedure:

The Ross procedure is performed for children and adults as an alternative to prosthetic aortic valve placement. In this procedure, the pulmonary valve and root are harvested and placed in the aortic position, with re-implantation of the coronary arteries and placement of a right ventricle to pulmonary artery conduit. Evaluation after the Ross procedure requires visualization of the neo-aortic root, reimplanted coronary arteries and pulmonary conduit. As stated in prior sections above and in additional publications, cardiovascular CT performs well for these indications.²⁹³⁻²⁹⁶

Other Complex CHD (Stent, VAD, ECMO):

Cardiovascular CT may be considered for determination of stent integrity, diagnosis of aneurysm and other complications of stent placement and assessment of either airway or coronary compression from mass effect after intravascular intervention for aortic or pulmonary abnormalities.^{157, 297-301} Evaluation of coronary and vascular stents using cardiovascular CT is highly accurate when compared to traditional angiography.^{157, 298, 302-304} Beam hardening artifact and the partial volume effect may degrade in-stent evaluation for vessels less than 3 mm, although iterative reconstruction and appropriate kernel selection can improve image quality.³⁰⁵⁻³⁰⁷ Pediatric vascular stents were evaluated in an *in vitro* model found excellent correlation to conventional angiography in pediatric patients, despite at low tube potential settings and small stent sizes.²⁹⁸

Cardiovascular CT also provides diagnostic information (cannula positions, presence of thrombus, driveline infection) in patients on ECMO or with ventricular assist

device (VAD) support, a population in whom conventional imaging may be challenging.^{308, 309}

Use of CT for Functional Imaging

Echo and CMR are first line non-invasive modalities to assess ventricular function in patients with CHD, with cardiac CT offering an accurate alternative for this application in patients with CHD when contraindications or limitations to these modalities exist.^{211, 212,}

³¹⁰ Heart Failure is increasingly common in adults with CHD and serial evaluation is sometimes needed to help with medical management and advanced therapy decisions.³¹¹

Cardiac CT may be used for ventricular function analysis when data acquisition (“ECG trigger or ECG gating”) and image reconstruction are synchronized to the ECG and then reconstructed in a multiphase dataset. With a retrospectively ECG-gated helical protocol, ECG-based tube current modulation allows full radiation during a specified short portion of the cardiac cycle while tube current is reduced during the remainder of the cardiac cycle. This dose modulation protocol allows reconstruction of an end systolic dataset with sufficient image quality to detect the endocardial contours in addition to a high quality diastolic dataset. Prospectively ECG-triggered datasets can also be used for functional analysis, as long as the data acquisition window captures both end-systole and end-diastole. Several publications have demonstrated that both right and left ventricular systolic function can be measured by cardiac CT with accuracy

comparable to CMR.^{18,257,312-316} An assessment of MRI vs DSCT found that the function results were considered interchangeable.^{210, 317, 318} When estimates of ventricular volumes and calculation of ejection fraction were compared to known volumes using a moving heart phantom and standard clinical imaging protocols, DSCT performed better than both MRI or 64 slice CT. The accuracy of 64 slice CT was dependent on heart rate, however.³¹⁹ The accuracy of CT for functional analysis will depend on the temporal resolution available on the scanner platform and scan sequence used. For functional imaging, beta blockade is not typically required unless high resolution distal coronary imaging is also needed from the fully radiated phase of the dataset.

Since 7-10 mm slice thickness is sufficient for both RV and LV quantification, lower-dose scans yield evaluable datasets for this purpose.^{320, 321} Heart failure associated with ventricular pacing is the largest indication for biventricular pacing in pediatric patients and CHD.³²² Cardiac CT has been shown to evaluate regional wall motion associated with ventricular pacing in a small cohort of patients.³²³

Valvular stenosis, regurgitation, prosthetic valve and perivalvular leak:

Many patients with CHD need repeat valve intervention, commonly on more than one valve.¹³¹ In young patients undergoing mitral valve replacement, 50% will require re-replacement within 10 years, and 15% require pacemaker placement within one month of valve placement.^{324, 325} There are several studies showing the utility of cardiac CT for evaluation of native and mechanical valve stenosis and insufficiency, perivalvular leak, thrombosis, abscess and endocarditis.³²⁶⁻³³³ Stroke volume differences between

ventricles calculated from a functional dataset may be used to quantify the severity of valvular regurgitation if correlated closely with echocardiographic findings.²¹³

Quantification of regurgitation is not possible in single ventricle patients or in patients with more than one regurgitant lesion or intracardiac shunt. The total difference in stroke volume is evaluable, with reliance on other modalities for assessment of the contribution of each lesion (see section on function imaging). Assessment of coronary artery anatomy in relationship to the mitral valve (occasionally supraannular) is needed for surgical planning at the time of replacement. In patients with pacemakers or previously replaced mechanical valve, complete pre-operative assessment of anatomy, including coronary artery anatomy, is often required and can be performed with cardiovascular CT.

Sternal Re-entry in High Risk Patients

It has long been appreciated that reoperation in patients with CHD carry increased risk of serious vascular injury upon sternal reentry, sometimes requiring emergent peripheral cannulation for cardiopulmonary bypass.^{334, 335} While a recent study suggests that the risk has decreased with improved surgical techniques, presence of right ventricle to pulmonary artery conduits and increasing number of sternotomies remain risk factors for injury.³³⁶ It is critical to define the proximity of the coronary arteries and cardiac structures to the posterior sternum prior to repeat sternotomy for consideration of peripheral bypass at the time of sternal entry.³³⁷ Some authors advocate cardiovascular CT prior to repeat sternotomy in select patients.³³⁸ While CMR can identify the

relationship between vascular structures and the sternum, artifact resulting from sternal wires limits its ability to define this relationship with the clarity afforded by cardiovascular CT.

RISK OF CT IN THE CURRENT ERA:

Sedation/anesthesia:

The time required to image the thorax ranges from 0.25 to 10 seconds for 64-320 slice CT scanners depending on factors such as the need for ECG gating and scan length. The newest generation scanners acquire the dataset in a fraction of a second or a single heartbeat, reducing or eliminating the need for sedation and suspended respiration for a majority of indications.¹⁴ Studies have shown that images acquired without sedation in neonates and with conscious sedation in toddlers and young children yield adequate to excellent image quality.^{10, 14} When image acquisition requires breath holding, only a single and short duration suspension of respiration is needed.^{10, 14, 189, 339} Most patients age ≥ 7 years can reliably cooperate with scanning instructions. General anesthesia (GA) may be required for the youngest patients who cannot sustain a breath hold when required for scan sequences that acquires data over several heart beats. This includes detailed coronary artery imaging at high heart rates and ventricular function measurement. When GA is needed, no change in ventilator management or specialized equipment is needed for cardiovascular CT acquisition. For older generation scanners with image acquisition times of 6-10 seconds, sedation or anesthesia may still be required in children and developmentally delayed patients of any

age unable to cooperate with breath hold instructions to eliminate motion artifact even for non-ECG triggered scans.

In pediatric patients, general anesthesia (GA) confers risks of both procedural complication as well as the potential for long-term adverse neurodevelopmental outcome.³⁴⁰ In a multi institutional study, those with congenital heart disease in anesthesia class 3 or above were at highest risk for a procedural adverse event with GA.^{277, 341} The risk of cardiac arrest with GA is highest in the youngest patients and in those with unrepaired single ventricle heart disease, pulmonary hypertension, left ventricular outflow tract obstruction and cardiomyopathy.^{276, 341} In patients with congenital heart disease, the risk of GA has been shown to be higher when performed outside of the operating room.^{341, 342} In a study examining the complications associated with CMR, the use of GA significantly increased the risk of adverse events, with an odds ratio of 3.9.³⁴²⁻³⁴⁴

Anesthesia exposure in young patients may adversely affect long term cognitive and behavioral outcomes, particularly those exposed to prolonged or multiple anesthetics before age 2 years.³⁴⁵⁻³⁵¹ This concern is most relevant for CHD patients who will undergo multiple diagnostic evaluations and palliative interventions in the first year of life that will require anesthesia, such as patients who have TOF with pulmonary artery atresia or single ventricle heart disease. For patients who do require anesthesia the length of anesthesia for a CT study will be much shorter than for either CMR or cardiac catheterization.^{340, 349}

Infants with CHD referred for advanced cardiac imaging often require vasoactive infusions and/or mechanical ventilation in the intensive care unit. CMR in such patients requires conversion to MRI-compatible equipment, followed by 1-2 hours of anesthesia with multiple breath holding sequences.³⁴² Poor thermoregulation is also a challenge in small patients with prolonged anesthesia. CT can be performed quickly, patients can be returned to the intensive care unit within 15-30 minutes of leaving, and there is no need for conversion to and from specialized equipment. During the scan, patients are more accessible during computed tomography.³⁴⁰ CT can even be performed on patients on ECMO.³⁰⁸

Vascular Access:

IV access is required for contrast administration, usually delivered with a power injector. There is a low complication rate (0.2-0.4%) using power injectors with contrast injected via many different venous access devices in pediatric patients.³⁵² Power injection through central lines using low pressure limits and longer injection times is considered safe, but provides inadequate contrast opacification in patients weighing over 30 kg.³⁵³ A more recent study of peripheral IV power injection for CT examinations in children using 22 gauge angiocatheters in 443 of 557 children (range 18-24 gauge) at a median flow rate of 1.5 ml/sec reported two episodes of contrast extravasations treated conservatively (0.3%).³⁵⁴ Safe use of power injectors in neonates at low flow rates has been reported.¹⁰

Contrast Exposure:

Almost all cardiovascular examinations are performed with iodinated contrast. Typical exams require 1-2 ml/kg of contrast volume. The rate of adverse reaction from iodinated contrast administration is very low in adult patients, ranging from 0.1% to 1% in several studies.³⁵⁵⁻³⁵⁸ In several large reviews of pediatric age range patients the incidence of contrast reaction is also low (0.18-0.46%).^{359, 360} The incidence of contrast induced nephropathy is highest in patients with severely reduced renal function and use of pre-scan hydration may decrease the incidence of adverse renal effects.³⁶¹ If CT is required in the setting of renal failure, every effort should be made to withdraw nephrotoxic drugs, select low or iso-osmolar contrast media, use as little contrast as possible, and consider pre-scan hydration.³⁶² Gadolinium-enhanced CT studies have been reported in iodine allergic patients and the fairly low *k* edge of gadolinium is particularly suited to reduced kV imaging.³⁶³

Medications to Lower Heart Rate:

For coronary artery imaging, a heart rate below 60 beats per minute maximizes the potential for obtaining high quality images within a single diastolic interval and requires the lowest radiation exposure.^{364, 365} Even with beta blockade the heart rate will be elevated in small patients. Significant heart rate variability during the monitoring or acquisition phase of certain scan sequences will automatically widen the acquisition window. Pre-procedural medication can be used to decrease the overall heart rate or the variability with respiration. Different protocols for beta blockade have been

described and are effective for decreasing the heart rate and thus the required radiated interval of the cardiac cycle.³⁶⁶⁻³⁶⁸ Protocols specific to children have been described with effective heart rate control and excellent safety.^{10, 369} The safety of heart rate lowering medications must be assessed for each patient prior to administration. Hemodynamically unstable children may not tolerate the effects of beta blockade and are often imaged at their intrinsic heart rate. For heart rates above 60 beats per minute, images with minimum cardiac motion artifact may be obtained during either the end systolic or end diastolic phase of the cardiac cycle. Some scans obtained at higher heart rates will require a widened acquisition window and higher radiation doses.³⁷⁰⁻³⁷²

Radiation Exposure:

Ionizing radiation is fundamental to image creation with CT, and radiation exposure is thought to increase the risk of future development of cancer.³⁷³⁻³⁷⁶ A linear no threshold model has been adopted for medical radiation exposure. The risk of radiation exposure is particularly relevant for young patients due to both their longer expected lifespan and greater radiation sensitivity compared to adults. The radiation exposure required for cardiac CT has decreased significantly in the last number of years with the introduction of a number of dose reduction techniques.^{377, 378} These include the availability of low tube potential (e.g, 70, 80, 90 or 100 kV) settings, ECG-based tube current modulation and anatomic-based tube current modulation.^{10, 11, 13, 379-381} The introduction of iterative reconstruction algorithms allow for a reduction in tube current and radiation dose while

maintaining acceptable noise properties.^{15, 78, 339, 382-384} Improvements in detector technologies have also allowed radiation exposures to be lowered. To achieve a lower estimated dose in smaller patients, tube potential and tube current should be adjusted to patient size with 70 or 80 kV as the default tube potential. Retrospective ECG-gated helical scans should be reserved for evaluation of ventricular function and for detailed coronary artery assessment when arrhythmia is present.^{13, 365, 385, 386}

The most advanced CT scanner platforms can routinely achieve an effective radiation dose estimate of less than 1 milliSievert (mSv) for many congenital cardiac applications, even when using the size and age adjusted CT dose volume index (CTDIvol) and chest conversion factors.^{10,12, 13,16,17,387} The radiation dose estimate for an infant will be increased by a factor of seven over the standard adult estimate if the smaller phantom (16 cm vs 32cm) is used to determine CTDIvol, and an age adjusted chest conversion factor is used to convert this value into mSv.^{10,12,13,16,198,387,388} Size specific dose estimate (SSDE) is another radiation measurement used by some centers to estimate an individual organ dose from scanner output and patient specific chest measurements. The estimated organ dose cannot be used to determine a patient dose.³⁸⁹ When pediatric radiation dose estimates are reported, it should be stated which phantom size is used to estimate CTDIvol (16cm or 32 cm) and which age and chest conversion factors are used. This will allow equivalent comparisons of radiation dose estimates despite the variability in reporting of scanner output and calculation of dose in pediatric patients.

ECG-gated cardiac CT studies have historically yielded higher radiation doses using older retrospective ECG triggering techniques.³⁹⁰ A study published in 2011, however, shows consistently lower doses for 64-slice CT than for conventional angiography.³⁹¹ A recent study documented a median effective dose of 1 mSv for ECG-gated helical and ECG-triggered axial coronary CTA in a wide range of pediatric patients.¹⁰ CT now has the potential to deliver 10-15 fold less radiation than cardiac catheterization when used by experienced users at centers with modern 64-slice or greater CT scanners and with careful attention to scan parameters.^{391, 392} However, if scan parameters are not carefully adjusted for clinical indication and patient size, radiation doses may be significantly higher. A recent publication estimates cumulative radiation exposure from cardiac diagnostics for patients less than six years of age, and shows relatively high radiation exposure for patients undergoing repeat diagnostic examinations such as transplant recipients and those with single ventricle heart disease.³⁹³ In this study, ECG gated CT scans were estimated to deliver twice the radiation dose of cardiac catheterization. Such findings underscore the importance of meticulous attention to dose reduction techniques with every cardiovascular CT examination to minimize both procedural and cumulative radiation exposure. Scanner output recommendations are often for high resolution coronary artery imaging. For evaluation of larger cardiac structures this level of detail (and radiation dose) are not needed for clinical decision making. Congenital cardiac CT imagers should communicate with referring cardiologists to determine the minimum image quality required that will deliver the diagnostically important information. The image quality required for a detailed coronary artery scan is not needed for the majority of CHD scan

indications. Recent recommendations suggest that the risks and benefits of cardiac imaging should be discussed as part of informed consent, and that radiation parameters should be included in procedural reporting.³⁹⁴

RECOMMENDATIONS FOR CT IMAGING IN CHD:

Cardiac CT will have an important role in the future of congenital cardiac imaging. The tables below summarize consensus recommendations for the imaging environment and required knowledge to perform high quality CT in patients with CHD, and clinical scenarios where CT may be used.

Table A: Optimal Imaging Environment for Cardiovascular CT in CHD

All cardiac imaging modalities are available so that the test with the least risk can be performed for a specific clinical indication
Close collaboration & communication is present among surgeons, clinical cardiologists and imagers
All patient clinical information is accessible to allow understanding of the clinical indication and potential management options for the patient
Scan protocols can be designed and adjusted to extract maximum clinical information at minimum procedural risk
Technologists are experienced in cardiac CT and comfortable with varied cardiac scan modes
Easy access to pacemaker programming to allow rate and mode adjustment
Nursing support to facilitate administration of medication for heart rate control when necessary in patients with and without permanent pacemakers, and to provide appropriate monitoring for any side effects
Access to all forms of prior imaging (echocardiography, angiography, nuclear, CMR) so that a targeted evaluation may be performed for an individual patient

Post processing workstations capable of handling large multiphase data sets for advanced reconstructions
High-speed network to transfer large volume data sets from scanner to workstation
Immediate availability of advanced resuscitation equipment and resuscitation team appropriate for the size and age of the patient

Table B: Relevant Knowledge for the Performance of Cardiovascular CT in CHD

Cardiology knowledge required
Anatomy & physiology of CHD – natural and repaired
Surgical procedures used to palliate or repair CHD
Catheter interventions used to palliate or repair CHD
Material composition of the surgical materials or catheter devices used and the artifact produced in different imaging modalities (MRI and CT)
Common residual hemodynamic lesions following initial CHD repair
Indications for re-intervention (AHA/ACC/ESC/CCS guidelines)
Normal coronary anatomy
Congenital coronary anomalies and the indications for and methods of repair
Basic ECG knowledge and arrhythmia recognition (and impact on imaging strategy)
Pediatric and adult doses for heart rate lowering medications and sublingual nitroglycerin, and contraindications to these medications
CT knowledge required
Experience in congenital cardiac CT in addition to standard cardiac CT training. (For adults Level 2 or 3 training, for pediatrics there are no current educational standards for cardiac CT)
Scanning principles and scan modes, including the different capabilities of individual scanner platforms
Contrast injection protocols adjusted for both patient size and cardiac pathology
Prophylaxis against and treatment of minor and major contrast reactions
Radiation physics and basics of radiation dose measurement
Radiation dose reduction strategies and individualized scan planning
Familiarity and competence with post-processing methods and software
Familiarity with standards for quantification and reporting in CHD

Table C: Situations in which Cardiovascular CT may be appropriate in CHD

Presence of CMR unsafe implant or foreign body (retained pacing leads, non-MR compatible pacemaker/defibrillator, neurostimulator)
Poor CMR image quality (known or expected) due to metallic artifact
Unable to fit in MRI scanner due to obesity, or severe claustrophobia

Neonate or young patient requiring evaluation of complex anatomy, particularly if considered higher risk for adverse event with sedation or anesthesia required for CMR, and the CT scan can be performed with no or limited sedation
Critically ill patient of any age that may not tolerate breath holding or length of CMR scan
Evaluation of ventricular assist device or ECMO cannula positioning
Patient requiring CT for evaluation of extra-cardiac anatomy in addition to CHD (e.g. lung parenchyma, airway, skeletal abnormality)
Pre-operative patients with prior sternotomy considered high risk for vascular injury with sternal reentry due to an anterior coronary artery, conduit, or sternal adhesions
Evaluation of prosthetic valve function or structural integrity (calcification, stenosis, coaptation defect, leaflet immobility, paravalvular leak, endocarditis or clot)
Evaluation of calcification within vessels and surgical conduits prior to catheter-based intervention (e.g. balloon angioplasty, transcatheter valve replacement, stent placement).
Coronary artery imaging in CHD: <ul style="list-style-type: none">a) Patient needing detailed pre-operative coronary artery evaluation in addition to assessment of complex cardiac anatomyb) Patient with symptoms and signs suggestive of atherosclerotic coronary artery disease and a history of CHD, prior coronary intervention, or high risk Kawasaki diseasec) Young symptomatic patients with known or suspected coronary anomaly, particularly if CMR is unlikely to provide complete assessment or more likely to require anesthesiad) Delineation of coronary anatomy prior to surgical or percutaneous pulmonary valve implantatione) Evaluation of coronary artery after any surgery requiring coronary artery manipulation or reimplantation

1. Sigal-Cinqualbre A, Lambert V, Ronhean A, and Paul JF. [Role of MSCT and MRI in the diagnosis of congenital heart disease]. *Arch Pediatr*. 2011;18:617-27.
2. Achenbach S, Barkhausen J, Beer M, Beerbaum P, Dill T, Eichhorn J, Fratz S, Gutberlet M, Hoffmann M, Huber A, et al. [Consensus recommendations of the German Radiology Society (DRG), the German Cardiac Society (DGK) and the German Society for Pediatric Cardiology (DGPK) on the use of cardiac imaging with computed tomography and magnetic resonance imaging]. *Rofo*. 2012;184:345-68.
3. Crean A. Cardiovascular MR and CT in congenital heart disease. *Heart*. 2007;93:1637-47.
4. Chan FP. MR and CT imaging of the pediatric patient with structural heart disease. *Semin Thorac Cardiovasc Surg*. 2008;20:393-9.
5. Dillman JR, and Hernandez RJ. Role of CT in the evaluation of congenital cardiovascular disease in children. *AJR Am J Roentgenol*. 2009;192:1219-31.
6. Siegel MJ, Schmidt B, Bradley D, Suess C, and Hildebolt C. Radiation dose and image quality in pediatric CT: effect of technical factors and phantom size and shape. *Radiology*. 2004;233:515-22.
7. Siegel MJ. Cardiac CTA: congenital heart disease. *Pediatr Radiol*. 2008;38 Suppl 2:S200-4.
8. Goo HW, Park IS, Ko JK, Kim YH, Seo DM, and Park JJ. Computed tomography for the diagnosis of congenital heart disease in pediatric and adult patients. *Int J Cardiovasc Imaging*. 2005;21:347-65; discussion 67.
9. Flohr TG, Leng S, Yu L, Aiemendinger T, Bruder H, Petersilka M, Eusemann CD, Stierstorfer K, Schmidt B, and McCollough CH. Dual-source spiral CT with pitch up to 3.2 and 75 ms temporal resolution: image reconstruction and assessment of image quality. *Med Phys*. 2009;36:5641-53.
10. Han BK, Lindberg J, Grant K, Schwartz RS, and Lesser JR. Accuracy and safety of high pitch computed tomography imaging in young children with complex congenital heart disease. *Am J Cardiol*. 2011;107:1541-6.
11. Huang MP, Liang CH, Zhao ZJ, Liu H, Li JL, Zhang JE, Cui YH, Yang L, Liu QS, Ivanc TB, et al. Evaluation of image quality and radiation dose at prospective ECG-triggered axial 256-slice multi-detector CT in infants with congenital heart disease. *Pediatr Radiol*. 2011;41:858-66.
12. Ben Saad M, Rohnean A, Sigal-Cinqualbre A, Adler G, and Paul JF. Evaluation of image quality and radiation dose of thoracic and coronary dual-source CT in 110 infants with congenital heart disease. *Pediatr Radiol*. 2009;39:668-76.

13. Paul JF, Rohnean A, Elfassy E, and Sigal-Cinqualbre A. Radiation dose for thoracic and coronary step-and-shoot CT using a 128-slice dual-source machine in infants and small children with congenital heart disease. *Pediatr Radiol*. 2011;41:244-9.
14. Lell MM, May M, Deak P, Alibek S, Kuefner M, Kuettner A, Kohler H, Achenbach S, Uder M, and Radkow T. High-pitch spiral computed tomography: effect on image quality and radiation dose in pediatric chest computed tomography. *Invest Radiol*. 2011;46:116-23.
15. Han BK, Grant KL, Garberich R, Sedlmair M, Lindberg J, and Lesser JR. Assessment of an iterative reconstruction algorithm (SAFIRE) on image quality in pediatric cardiac CT datasets. *J Cardiovasc Comput Tomogr*. 2012;6:200-4.
16. Pache G, Grohmann J, Bulla S, Arnold R, Stiller B, Schlensak C, Langer M, and Blanke P. Prospective electrocardiography-triggered CT angiography of the great thoracic vessels in infants and toddlers with congenital heart disease: feasibility and image quality. *Eur J Radiol*. 2011;80:e440-5.
17. Xu J, Zhao H, Wang X, Bai Y, Liu L, Liu Y, Wei M, Li J, and Zheng M. Accuracy, image quality, and radiation dose of prospectively ECG-triggered high-pitch dual-source CT angiography in infants and children with complex coarctation of the aorta. *Acad Radiol*. 2014;21:1248-54.
18. Sharma A, Einstein AJ, Vallakati A, Arbab-Zadeh A, Mukherjee D, and Lichstein E. Meta-analysis of global left ventricular function comparing multidetector computed tomography with cardiac magnetic resonance imaging. *Am J Cardiol*. 2014;113:731-8.
19. Khairy P, Van Hare GF, Balaji S, Berul CI, Cecchin F, Cohen MI, Daniels CJ, Deal BJ, Dearani JA, Groot ND, et al. PACES/HRS Expert Consensus Statement on the Recognition and Management of Arrhythmias in Adult Congenital Heart Disease. *Heart Rhythm*. 2014. Oct;11(10):e102-65
20. Prakash A, Powell AJ, and Geva T. Multimodality noninvasive imaging for assessment of congenital heart disease. *Circ Cardiovasc Imaging*. 2010;3:112-25.
21. Han BK, Lesser AM, Vezmar M, Rosenthal K, Rutten-Ramos S, Lindberg J, Caye D, and Lesser JR. Cardiovascular imaging trends in congenital heart disease: a single center experience. *J Cardiovasc Comput Tomogr*. 2013;7:361-6.
22. Khairy P, Ionescu-Iltu R, Mackie AS, Abrahamowicz M, Pilote L, and Marelli AJ. Changing mortality in congenital heart disease. *Journal of the American College of Cardiology*. 2010;56:1149-57.
23. Warnes CA, Williams RG, Bashore TM, Child JS, Connolly HM, Dearani JA, del Nido P, Fasules JW, Graham TP, Jr., Hijazi ZM, et al. ACC/AHA 2008 Guidelines for the Management of Adults with Congenital Heart Disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines on the management of adults with congenital heart disease). *Circulation*. 2008;118:e714-833.

24. Marelli AJ, Mackie AS, Ionescu-Iltu R, Rahme E, and Pilote L. Congenital heart disease in the general population: changing prevalence and age distribution. *Circulation*. 2007;115:163-72.
25. Marelli AJ, Ionescu-Iltu R, Mackie AS, Guo L, Dendukuri N, and Kaouache M. Lifetime prevalence of congenital heart disease in the general population from 2000 to 2010. *Circulation*. 2014;130:749-56.
26. Jacobs JP JM, Mavroudis C, Tchervenkov CI, Pasquali SK. Executive Summary: The Society of Thoracic Surgeons Congenital Heart Surgery Database - Twentieth Harvest *The Society of Thoracic Surgeons (STS) and Duke Clinical Research Institute (DCRI)*. (January 1, 2010 – December 31, 2013);Duke University Medical Center, Durham, North Carolina, United States: Spring 2014 Harvest. Table 1, pg. 1.
27. Stulak JM, Dearani JA, Burkhart HM, Ammash NM, Phillips SD, and Schaff HV. Coronary artery disease in adult congenital heart disease: outcome after coronary artery bypass grafting. *Ann Thorac Surg*. 2012;93:116-22; discussion 22-3.
28. Afilalo J, Therrien J, Pilote L, Ionescu-Iltu R, Martucci G, and Marelli AJ. Geriatric congenital heart disease: burden of disease and predictors of mortality. *J Am Coll Cardiol*. 2011;58:1509-15.
29. Tutarel O, Kempny A, Alonso-Gonzalez R, Jabbour R, Li W, Uebing A, Dimopoulos K, Swan L, Gatzoulis MA, and Diller GP. Congenital heart disease beyond the age of 60: emergence of a new population with high resource utilization, high morbidity, and high mortality. *European heart journal*. 2014;35:725-32.
30. Warnes CA. The adult with congenital heart disease: born to be bad? *J Am Coll Cardiol*. 2005;46:1-8.
31. van der Bom T, Zomer AC, Zwinderman AH, Meijboom FJ, Bouma BJ, and Mulder BJ. The changing epidemiology of congenital heart disease. *Nat Rev Cardiol*. 2011;8:50-60.
32. Mackie AS, Pilote L, Ionescu-Iltu R, Rahme E, and Marelli AJ. Health care resource utilization in adults with congenital heart disease. *Am J Cardiol*. 2007;99:839-43.
33. Holst KA, Dearani JA, Burkhart HM, Connolly HM, Warnes CA, Li Z, and Schaff HV. Risk factors and early outcomes of multiple reoperations in adults with congenital heart disease. *Ann Thorac Surg*. 2011;92:122-8; discussion 9-30.
34. Feltes TF, Bacha E, Beekman RH, 3rd, Cheatham JP, Feinstein JA, Gomes AS, Hijazi ZM, Ing FF, de Moor M, Morrow WR, et al. Indications for cardiac catheterization and intervention in pediatric cardiac disease: a scientific statement from the American Heart Association. *Circulation*. 2011;123:2607-52.
35. Tworetzky W, McElhinney DB, Brook MM, Reddy VM, Hanley FL, and Silverman NH. Echocardiographic diagnosis alone for the complete repair of major congenital heart defects. *J Am Coll Cardiol*. 1999;33:228-33.

36. Marino B, Corno A, Carotti A, Pasquini L, Giannico S, Guccione P, Bevilacqua M, De Simone G, and Marcelletti C. Pediatric cardiac surgery guided by echocardiography. Established indications and new trends. *Scand J Thorac Cardiovasc Surg*. 1990;24:197-201.
37. Geva T, Greil GF, Marshall AC, Landzberg M, and Powell AJ. Gadolinium-enhanced 3-dimensional magnetic resonance angiography of pulmonary blood supply in patients with complex pulmonary stenosis or atresia: comparison with x-ray angiography. *Circulation*. 2002;106:473-8.
38. Greil GF, Powell AJ, Gildein HP, and Geva T. Gadolinium-enhanced three-dimensional magnetic resonance angiography of pulmonary and systemic venous anomalies. *J Am Coll Cardiol*. 2002;39:335-41.
39. Stern KW, McElhinney DB, Gauvreau K, Geva T, and Brown DW. Echocardiographic evaluation before bidirectional Glenn operation in functional single-ventricle heart disease: comparison to catheter angiography. *Circ Cardiovasc Imaging*. 2011;4:498-505.
40. Margossian R, Schwartz ML, Prakash A, Wruck L, Colan SD, Atz AM, Bradley TJ, Fogel MA, Hurwitz LM, Marcus E, et al. Comparison of echocardiographic and cardiac magnetic resonance imaging measurements of functional single ventricular volumes, mass, and ejection fraction (from the Pediatric Heart Network Fontan Cross-Sectional Study). *Am J Cardiol*. 2009;104:419-28.
41. Kilner PJ, Geva T, Kaemmerer H, Trindade PT, Schwitter J, and Webb GD. Recommendations for cardiovascular magnetic resonance in adults with congenital heart disease from the respective working groups of the European Society of Cardiology. *Eur Heart J*. 2010;31:794-805.
42. Powell AJ, Maier SE, Chung T, and Geva T. Phase-velocity cine magnetic resonance imaging measurement of pulsatile blood flow in children and young adults: in vitro and in vivo validation. *Pediatr Cardiol*. 2000;21:104-10.
43. Mooij CF, de Wit CJ, Graham DA, Powell AJ, and Geva T. Reproducibility of MRI measurements of right ventricular size and function in patients with normal and dilated ventricles. *J Magn Reson Imaging*. 2008;28:67-73.
44. Prakash A, Powell AJ, Krishnamurthy R, and Geva T. Magnetic resonance imaging evaluation of myocardial perfusion and viability in congenital and acquired pediatric heart disease. *Am J Cardiol*. 2004;93:657-61.
45. Salerno M, and Beller GA. Noninvasive assessment of myocardial perfusion. *Circ Cardiovasc Imaging*. 2009;2:412-24.
46. Pennell DJ. Cardiovascular magnetic resonance. *Circulation*. 2010;121:692-705.

47. Voit D, Zhang S, Unterberg-Buchwald C, Sohns JM, Lotz J, and Frahm J. Real-time cardiovascular magnetic resonance at 1.5 T using balanced SSFP and 40 ms resolution. *J Cardiovasc Magn Reson*. 2013;15:79.
48. Piehler KM, Wong TC, Puntill KS, Zareba KM, Lin K, Harris DM, Deible CR, Lacomis JM, Czeyda-Pommersheim F, Cook SC, et al. Free-breathing, motion-corrected late gadolinium enhancement is robust and extends risk stratification to vulnerable patients. *Circ Cardiovasc Imaging*. 2013;6:423-32.
49. Xu J, Kim D, Otazo R, Srichai MB, Lim RP, Axel L, McGorty KA, Niendorf T, and Sodickson DK. Towards a five-minute comprehensive cardiac MR examination using highly accelerated parallel imaging with a 32-element coil array: feasibility and initial comparative evaluation. *J Magn Reson Imaging*. 2013;38:180-8.
50. Taylor AM. Cardiac imaging: MR or CT? Which to use when. *Pediatr Radiol*. 2008;38 Suppl 3:S433-8.
51. Tsai-Goodman B, Geva T, Odegard KC, Sena LM, and Powell AJ. Clinical role, accuracy, and technical aspects of cardiovascular magnetic resonance imaging in infants. *Am J Cardiol*. 2004;94:69-74.
52. Levine GN, Gomes AS, Arai AE, Bluemke DA, Flamm SD, Kanal E, Manning WJ, Martin ET, Smith JM, Wilke N, et al. Safety of magnetic resonance imaging in patients with cardiovascular devices: an American Heart Association scientific statement from the Committee on Diagnostic and Interventional Cardiac Catheterization, Council on Clinical Cardiology, and the Council on Cardiovascular Radiology and Intervention: endorsed by the American College of Cardiology Foundation, the North American Society for Cardiac Imaging, and the Society for Cardiovascular Magnetic Resonance. *Circulation*. 2007;116:2878-91.
53. Hasebroock KM, and Serkova NJ. Toxicity of MRI and CT contrast agents. *Expert Opin Drug Metab Toxicol*. 2009;5:403-16.
54. Ersoy H, and Rybicki FJ. Biochemical safety profiles of gadolinium-based extracellular contrast agents and nephrogenic systemic fibrosis. *J Magn Reson Imaging*. 2007;26:1190-7.
55. Garg R, Powell AJ, Sena L, Marshall AC, and Geva T. Effects of metallic implants on magnetic resonance imaging evaluation of Fontan palliation. *Am J Cardiol*. 2005;95:688-91.
56. Khanna AD, Warnes CA, Phillips SD, Lin G, and Brady PA. Single-center experience with implantable cardioverter-defibrillators in adults with complex congenital heart disease. *Am J Cardiol*. 2011;108:729-34.
57. Kella DK, Merchant FM, Veledar E, Book W, and Lloyd MS. Lesion-specific differences for implantable cardioverter defibrillator therapies in adults with congenital heart disease. *Pacing Clin Electrophysiol*. 2014;37:1492-8.

58. Mondesert B, and Khairy P. Implantable cardioverter-defibrillators in congenital heart disease. *Current opinion in cardiology*. 2014;29:45-52.
59. Cronin EM, Mahon N, and Wilkoff BL. MRI in patients with cardiac implantable electronic devices. *Expert Rev Med Devices*. 2012;9:139-46.
60. Nordbeck P, and Bauer WR. [Safety of cardiac pacemakers and implantable cardioverter-defibrillators in magnetic resonance imaging. Assessment of the aggregate function at 1.5 tesla]. *Dtsch Med Wochenschr*. 2008;133:624-8.
61. McLeod CJ, Attenhofer Jost CH, Warnes CA, Hodge D, 2nd, Hyberger L, Connolly HM, Asirvatham SJ, Dearani JA, Hayes DL, and Ammash NM. Epicardial versus endocardial permanent pacing in adults with congenital heart disease. *J Interv Card Electrophysiol*. 2010;28:235-43.
62. Siegel MJ, Bhalla S, Gutierrez FR, and Billadello JB. MDCT of postoperative anatomy and complications in adults with cyanotic heart disease. *AJR Am J Roentgenol*. 2005;184:241-7.
63. Chan FP. MR and CT imaging of the pediatric patient with structural heart disease. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu*. 2009:99-105.
64. Bean MJ, Pannu H, and Fishman EK. Three-dimensional computed tomographic imaging of complex congenital cardiovascular abnormalities. *J Comput Assist Tomogr*. 2005;29:721-4.
65. Hlavacek AM. Imaging of congenital cardiovascular disease: the case for computed tomography. *J Thorac Imaging*. 2010;25:247-55.
66. Hughes D, Jr., and Siegel MJ. Computed tomography of adult congenital heart disease. *Radiol Clin North Am*. 2010;48:817-35.
67. Cook SC, Dyke PC, 2nd, and Raman SV. Management of adults with congenital heart disease with cardiovascular computed tomography. *J Cardiovasc Comput Tomogr*. 2008;2:12-22.
68. Ellis AR, Mulvihill D, Bradley SM, and Hlavacek AM. Utility of computed tomographic angiography in the pre-operative planning for initial and repeat congenital cardiovascular surgery. *Cardiol Young*. 2010;20:262-8.
69. Kilner PJ. Imaging congenital heart disease in adults. *Br J Radiol*. 2011;84 Spec No 3:S258-68.
70. Marcus ML, Stanford W, Hajduczuk ZD, and Weiss RM. Ultrafast computed tomography in the diagnosis of cardiac disease. *Am J Cardiol*. 1989;64:54E-9E.

71. Schlesinger AE, and Hernandez RJ. Congenital heart disease: applications of computed tomography and magnetic resonance imaging. *Semin Ultrasound CT MR*. 1991;12:11-27.
72. Chomka EV, and Brundage BH. Cardiovascular ultrafast computed tomographic angiography. *Am J Card Imaging*. 1993;7:252-64.
73. Fisher MR, Lipton MJ, and Higgins CB. Magnetic resonance imaging and computed tomography in congenital heart disease. *Semin Roentgenol*. 1985;20:272-82.
74. Bierhals AJ, Rossini S, Woodard PK, Javidan-Nejad C, Billadello JJ, Bhalla S, and Gutierrez FR. Segmental analysis of congenital heart disease: putting the "puzzle" together with computed tomography. *Int J Cardiovasc Imaging*. 2014.
75. Al-Mousily F, Shifrin RY, Fricker FJ, Feranec N, Quinn NS, and Chandran A. Use of 320-detector computed tomographic angiography for infants and young children with congenital heart disease. *Pediatr Cardiol*. 2011;32:426-32.
76. Darabian S, Zeb I, Rezaeian P, Razipour A, and Budoff M. Use of noninvasive imaging in the evaluation of coarctation of aorta. *J Comput Assist Tomogr*. 2013;37:75-8.
77. Ghoshhajra BB, Sidhu MS, El-Sherief A, Rojas C, Yeh DD, Engel LC, Liberthson R, Abbara S, and Bhatt A. Adult congenital heart disease imaging with second-generation dual-source computed tomography: initial experiences and findings. *Congenit Heart Dis*. 2012;7:516-25.
78. Goo HW. Cardiac MDCT in children: CT technology overview and interpretation. *Radiol Clin North Am*. 2011;49:997-1010.
79. Hoey ET, Ganeshan A, Nadar SK, and Gulati GS. Evaluation of the aortic root with MRI and MDCT angiography: spectrum of disease findings. *AJR Am J Roentgenol*. 2012;199:W175-86.
80. Ihlenburg S, Rompel O, Rueffer A, Purbojo A, Cesnjevar R, Dittrich S, and Gloeckler M. Dual source computed tomography in patients with congenital heart disease. *Thorac Cardiovasc Surg*. 2014;62:203-10.
81. Ko SM, Song MG, and Hwang HK. Bicuspid aortic valve: spectrum of imaging findings at cardiac MDCT and cardiovascular MRI. *AJR Am J Roentgenol*. 2012;198:89-97.
82. Leschka S, Oechslin E, Husmann L, Desbiolles L, Marincek B, Genoni M, Pretre R, Jenni R, Wildermuth S, and Alkadhi H. Pre- and postoperative evaluation of congenital heart disease in children and adults with 64-section CT. *Radiographics*. 2007;27:829-46.
83. Nicol ED, Gatzoulis M, Padley SP, and Rubens M. Assessment of adult congenital heart disease with multi-detector computed tomography: beyond coronary lumenography. *Clin Radiol*. 2007;62:518-27.

84. Orwat S, Diller GP, and Baumgartner H. Imaging of congenital heart disease in adults: choice of modalities. *Eur Heart J Cardiovasc Imaging*. 2014;15:6-17.
85. Siripornpitak S, Pornkul R, Khowsathit P, Layangool T, Promphan W, and Pongpanich B. Cardiac CT angiography in children with congenital heart disease. *Eur J Radiol*. 2013;82:1067-82.
86. Spevak PJ, Johnson PT, and Fishman EK. Surgically corrected congenital heart disease: utility of 64-MDCT. *AJR Am J Roentgenol*. 2008;191:854-61.
87. Sunidja AP, Prabhu SP, Lee EY, and Sena L. 64-row-MDCT evaluation of postoperative congenital heart disease in children: review of technique and imaging findings. *Semin Roentgenol*. 2012;47:66-78.
88. Watts JR, Jr., Sonavane SK, Singh SP, and Nath PH. Pictorial review of multidetector CT imaging of the preoperative evaluation of congenital heart disease. *Curr Probl Diagn Radiol*. 2013;42:40-56.
89. Wiant A, Nyberg E, and Gilkeson RC. CT evaluation of congenital heart disease in adults. *AJR Am J Roentgenol*. 2009;193:388-96.
90. Budoff MJ, Dowe D, Jollis JG, Gitter M, Sutherland J, Halamert E, Scherer M, Bellinger R, Martin A, Benton R, et al. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. *J Am Coll Cardiol*. 2008;52:1724-32.
91. Dewey M, Zimmermann E, Deissenrieder F, Laule M, Dubel HP, Schlattmann P, Knebel F, Rutsch W, and Hamm B. Noninvasive coronary angiography by 320-row computed tomography with lower radiation exposure and maintained diagnostic accuracy: comparison of results with cardiac catheterization in a head-to-head pilot investigation. *Circulation*. 2009;120:867-75.
92. Hoffmann U, Bamberg F, Chae CU, Nichols JH, Rogers IS, Seneviratne SK, Truong QA, Cury RC, Abbara S, Shapiro MD, et al. Coronary computed tomography angiography for early triage of patients with acute chest pain: the ROMICAT (Rule Out Myocardial Infarction using Computer Assisted Tomography) trial. *J Am Coll Cardiol*. 2009;53:1642-50.
93. Hulten EA, Carbonaro S, Petrillo SP, Mitchell JD, and Villines TC. Prognostic value of cardiac computed tomography angiography: a systematic review and meta-analysis. *J Am Coll Cardiol*. 2011;57:1237-47.
94. Abbara S, Arbab-Zadeh A, Callister TQ, Desai MY, Mamuya W, Thomson L, and Weigold WG. SCCT guidelines for performance of coronary computed tomographic

- angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee. *J Cardiovasc Comput Tomogr*. 2009;3:190-204.
95. Leipsic J, Abbara S, Achenbach S, Cury R, Earls JP, Mancini GJ, Nieman K, Pontone G, and Raff GL. SCCT guidelines for the interpretation and reporting of coronary CT angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee. *J Cardiovasc Comput Tomogr*. 2014;8:342-58.
 96. Zhang LJ, Zhou CS, Wang Y, Jin Z, Yu W, Zhang Z, Zhang B, Fang X, Cui X, Li K, et al. Prevalence and types of coronary to pulmonary artery fistula in a Chinese population at dual-source CT coronary angiography. *Acta Radiol*. 2014;55:1031-9.
 97. Gupta R, Marwah A, and Shrivastva S. Anomalous origin of right coronary artery from pulmonary artery. *Ann Pediatr Cardiol*. 2012;5:95-6.
 98. Kuribayashi S, Ootaki M, Tsuji M, Matsuyama S, Iwasaki H, and Oota T. Coronary angiographic abnormalities in mucocutaneous lymph node syndrome: acute findings and long-term follow-up. *Radiology*. 1989;172:629-33.
 99. Chao BT, Wang XM, Wu LB, Chen J, Cheng ZP, Wu DW, and Duan YH. Diagnostic value of dual-source CT in Kawasaki disease. *Chin Med J (Engl)*. 123:670-4.
 100. Chu WC, Mok GC, Lam WW, Yam MC, and Sung RY. Assessment of coronary artery aneurysms in paediatric patients with Kawasaki disease by multidetector row CT angiography: feasibility and comparison with 2D echocardiography. *Pediatr Radiol*. 2006;36:1148-53.
 101. Duan Y, Wang X, Cheng Z, Wu D, and Wu L. Application of prospective ECG-triggered dual-source CT coronary angiography for infants and children with coronary artery aneurysms due to Kawasaki disease. *Br J Radiol*. 2012;85:e1190-7.
 102. Xing Y, Wang H, Yu X, Chen R, and Hou Y. Assessment of coronary artery lesions in children with Kawasaki disease: evaluation of MSCT in comparison with 2-D echocardiography. *Pediatr Radiol*. 2009;39:1209-15.
 103. Peng Y, Zeng J, Du Z, Sun G, and Guo H. Usefulness of 64-slice MDCT for follow-up of young children with coronary artery aneurysm due to Kawasaki disease: initial experience. *Eur J Radiol*. 2009;69:500-9.
 104. Yu Y, Sun K, Wang R, Li Y, Xue H, Yu L, Chen S, and Xi L. Comparison study of echocardiography and dual-source CT in diagnosis of coronary artery aneurysm due to Kawasaki disease: coronary artery disease. *Echocardiography*. 2011;28:1025-34.
 105. Arnold R, Ley S, Ley-Zaporozhan J, Eichhorn J, Schenk JP, Ulmer H, and Kauczor HU. Visualization of coronary arteries in patients after childhood Kawasaki syndrome: value of multidetector CT and MR imaging in comparison to conventional coronary catheterization. *Pediatr Radiol*. 2007;37:998-1006.

106. Carbone I, Cannata D, Algeri E, Galea N, Napoli A, De Zorzi A, Bosco G, D'Agostino R, Menezes L, Catalano C, et al. Adolescent Kawasaki disease: usefulness of 64-slice CT coronary angiography for follow-up investigation. *Pediatr Radiol*. 2011;41:1165-73.
107. Han BK, Lesser A, Rosenthal K, Dummer K, Grant K, and Newell M. Coronary computed tomographic angiographic findings in patients with Kawasaki disease. *Am J Cardiol*. 2014;114:1676-81.
108. Goo HW, Park IS, Ko JK, and Kim YH. Coronary CT angiography and MR angiography of Kawasaki disease. *Pediatr Radiol*. 2006;36:697-705.
109. Kim JW, and Goo HW. Coronary artery abnormalities in Kawasaki disease: comparison between CT and MR coronary angiography. *Acta Radiol*. 2013;54:156-63.
110. Maron BJ, Doerer JJ, Haas TS, Tierney DM, and Mueller FO. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. *Circulation*. 2009;119:1085-92.
111. Basso C, Maron BJ, Corrado D, and Thiene G. Clinical profile of congenital coronary artery anomalies with origin from the wrong aortic sinus leading to sudden death in young competitive athletes. *J Am Coll Cardiol*. 2000;35:1493-501.
112. Frescura C, Basso C, Thiene G, Corrado D, Pennelli T, Angelini A, and Daliento L. Anomalous origin of coronary arteries and risk of sudden death: a study based on an autopsy population of congenital heart disease. *Hum Pathol*. 1998;29:689-95.
113. Eckart RE, Shry EA, Burke AP, McNear JA, Appel DA, Castillo-Rojas LM, Avedissian L, Pearse LA, Potter RN, Tremaine L, et al. Sudden death in young adults: an autopsy-based series of a population undergoing active surveillance. *J Am Coll Cardiol*. 2011;58:1254-61.
114. Bishnoi RN, McMillan KN, and Thompson WR. Unusual sudden cardiac death from an anomalous left coronary artery from the right sinus of Valsalva. *Cardiol Young*. 2013:1-3.
115. Davis JA, Cecchin F, Jones TK, and Portman MA. Major coronary artery anomalies in a pediatric population: incidence and clinical importance. *J Am Coll Cardiol*. 2001;37:593-7.
116. Lytrivi ID, Wong AH, Ko HH, Chandra S, Nielsen JC, Srivastava S, Lai WW, and Parness IA. Echocardiographic diagnosis of clinically silent congenital coronary artery anomalies. *Int J Cardiol*. 2008;126:386-93.
117. Attili A, Hensley AK, Jones FD, Grabham J, and DiSessa TG. Echocardiography and coronary CT angiography imaging of variations in coronary anatomy and coronary abnormalities in athletic children: detection of coronary abnormalities that create a risk for sudden death. *Echocardiography*. 2013;30:225-33.

118. Kragel AH, and Roberts WC. Anomalous origin of either the right or left main coronary artery from the aorta with subsequent coursing between aorta and pulmonary trunk: analysis of 32 necropsy cases. *Am J Cardiol.* 1988;62:771-7.
119. Kaushal S, Backer CL, Popescu AR, Walker BL, Russell HM, Koenig PR, Rigsby CK, and Mavroudis C. Intramural coronary length correlates with symptoms in patients with anomalous aortic origin of the coronary artery. *Ann Thorac Surg.* 2011;92:986-91; discussion 91-2.
120. Lee HJ, Hong YJ, Kim HY, Lee J, Hur J, Choi BW, Chang HJ, Nam JE, Choe KO, and Kim YJ. Anomalous origin of the right coronary artery from the left coronary sinus with an interarterial course: subtypes and clinical importance. *Radiology.* 2012;262:101-8.
121. Cheng Z, Wang X, Duan Y, Wu L, Wu D, Liang C, Liu C, and Xu Z. Detection of coronary artery anomalies by dual-source CT coronary angiography. *Clin Radiol.* 2010;65:815-22.
122. Schmitt R, Froehner S, Brunn J, Wagner M, Brunner H, Cherevaty O, Gietzen F, Christopoulos G, Kerber S, and Fellner F. Congenital anomalies of the coronary arteries: imaging with contrast-enhanced, multidetector computed tomography. *Eur Radiol.* 2005;15:1110-21.
123. Shi H, Aschoff AJ, Brambs HJ, and Hoffmann MH. Multislice CT imaging of anomalous coronary arteries. *Eur Radiol.* 2004;14:2172-81.
124. Zhang LJ, Wu SY, Huang W, Zhou CS, and Lu GM. Anomalous origin of the right coronary artery originating from the left coronary sinus of valsalva with an interarterial course: diagnosis and dynamic evaluation using dual-source computed tomography. *J Comput Assist Tomogr.* 2009;33:348-53.
125. Lee BY, Song KS, Jung SE, Jung JI, Chun HJ, Park CB, Kim CK, Cho EJ, Jin U, and Jung HO. Anomalous right coronary artery originated from left coronary sinus with interarterial course: evaluation of the proximal segment on multidetector row computed tomography with clinical correlation. *J Comput Assist Tomogr.* 2009;33:755-62.
126. Opolski MP, Pregowski J, Kruk M, Witkowski A, Kwiecinska S, Lubienska E, Demkow M, Hryniewiecki T, Michalek P, Ruzyllo W, et al. Prevalence and characteristics of coronary anomalies originating from the opposite sinus of Valsalva in 8,522 patients referred for coronary computed tomography angiography. *Am J Cardiol.* 2013;111:1361-7.
127. Miller JA, Anavekar NS, El Yaman MM, Burkhart HM, Miller AJ, and Julsrud PR. Computed tomographic angiography identification of intramural segments in anomalous coronary arteries with interarterial course. *Int J Cardiovasc Imaging.* 2012;28:1525-32.
128. Beerbaum P, Sarikouch S, Laser KT, Greil G, Burchert W, and Korperich H. Coronary anomalies assessed by whole-heart isotropic 3D magnetic resonance imaging for cardiac morphology in congenital heart disease. *J Magn Reson Imaging.* 2009;29:320-7.

129. Prakken NH, Cramer MJ, Olimulder MA, Agostoni P, Mali WP, and Velthuis BK. Screening for proximal coronary artery anomalies with 3-dimensional MR coronary angiography. *Int J Cardiovasc Imaging*. 2010;26:701-10.
130. Yu FF, Lu B, Gao Y, Hou ZH, Schoepf UJ, Spearman JV, Cao HL, Sun ML, and Jiang SL. Congenital anomalies of coronary arteries in complex congenital heart disease: diagnosis and analysis with dual-source CT. *J Cardiovasc Comput Tomogr*. 2013;7:383-90.
131. Holst KA, Dearani JA, Burkhart HM, Connolly HM, Warnes CA, Li Z, and Schaff HV. Reoperative multivalve surgery in adult congenital heart disease. *Ann Thorac Surg*. 2013;95:1383-9.
132. Newburger JW, Takahashi M, Gerber MA, Gewitz MH, Tani LY, Burns JC, Shulman ST, Bolger AF, Ferrieri P, Baltimore RS, et al. Diagnosis, treatment, and long-term management of Kawasaki disease: a statement for health professionals from the Committee on Rheumatic Fever, Endocarditis, and Kawasaki Disease, Council on Cardiovascular Disease in the Young, American Heart Association. *Pediatrics*. 2004;114:1708-33.
133. Hirsch R, Gottliebson W, Crotty E, Fleck R, and Strife J. Computed tomography angiography with three-dimensional reconstruction for pulmonary venous definition in high-risk infants with congenital heart disease. *Congenit Heart Dis*. 2006;1:104-10.
134. Kim TH, Kim YM, Suh CH, Cho DJ, Park IS, Kim WH, and Lee YT. Helical CT angiography and three-dimensional reconstruction of total anomalous pulmonary venous connections in neonates and infants. *AJR Am J Roentgenol*. 2000;175:1381-6.
135. Dyer KT, Hlavacek AM, Meinel FG, De Cecco CN, McQuiston AD, Schoepf UJ, and Pietris NP. Imaging in congenital pulmonary vein anomalies: the role of computed tomography. *Pediatr Radiol*. 2014;44:1158-68.
136. Shen Q, Pa M, Hu X, and Wang J. Role of plain radiography and CT angiography in the evaluation of obstructed total anomalous pulmonary venous connection. *Pediatr Radiol*. 2013;43:827-35.
137. Bonelli-Sica JM, de la Mora-Cervantes R, Diaz-Zamudio M, Castillo-Castellon F, Ramirez-Carmona R, Velazquez-Moreno J, and Kimura-Hayama E. Dual-source 256-MDCT for diagnosis of anomalous pulmonary venous drainage in pediatric population. *AJR Am J Roentgenol*. 2013;200:W163-9.
138. Shiraishi I, Yamagishi M, Iwasaki N, Toiyama K, and Hamaoka K. Helical computed tomographic angiography in obstructed total anomalous pulmonary venous drainage. *Ann Thorac Surg*. 2001;71:1690-2.
139. Kasahara H, Aeba R, Tanami Y, and Yozu R. Multislice computed tomography is useful for evaluating partial anomalous pulmonary venous connection. *J Cardiothorac Surg*. 2010;5:40.

140. Oh KH, Choo KS, Lim SJ, Lee HD, Park JA, Jo MJ, Sung SC, Chang YH, Jeong DW, and Kim S. Multidetector CT evaluation of total anomalous pulmonary venous connections: comparison with echocardiography. *Pediatr Radiol*. 2009;39:950-4.
141. Ou P, Marini D, Celermajer DS, Agnoletti G, Vouhe P, Sidi D, Bonnet D, and Brunelle F. Non-invasive assessment of congenital pulmonary vein stenosis in children using cardiac-non-gated CT with 64-slice technology. *Eur J Radiol*. 2009;70:595-9.
142. Yao Q, Hu X, Pa M, and Huang G. Non-ECG-gated MDCTA of infracardiac total anomalous pulmonary venous connection in neonates and young infants. *Herz*. 2013;38:539-43.
143. Aminololama-Shakeri S, Wootton-Gorges SL, Pretzlaff RK, Reyes M, and Moore EH. Right-sided superior vena cava draining into the left atrium: a rare anomaly of systemic venous return. *Pediatr Radiol*. 2007;37:317-20.
144. Irwin RB, Greaves M, and Schmitt M. Left superior vena cava: revisited. *Eur Heart J Cardiovasc Imaging*. 2012;13:284-91.
145. Jun HJ. Interrupted inferior vena cava combined with partial anomalous pulmonary venous return drainage to the IVC in a 67-year-old adult. *J Card Surg*. 2013;28:28-30.
146. Kimura-Hayama ET, Melendez G, Mendizabal AL, Meave-Gonzalez A, Zambrana GF, and Corona-Villalobos CP. Uncommon congenital and acquired aortic diseases: role of multidetector CT angiography. *Radiographics*. 2010;30:79-98.
147. Ramos-Duran L, Nance JW, Jr., Schoepf UJ, Henzler T, Apfaltrer P, and Hlavacek AM. Developmental aortic arch anomalies in infants and children assessed with CT angiography. *AJR Am J Roentgenol*. 2012;198:W466-74.
148. Di Sessa TG, Di Sessa P, Gregory B, and Vranicar M. The use of 3D contrast-enhanced CT reconstructions to project images of vascular rings and coarctation of the aorta. *Echocardiography*. 2009;26:76-81.
149. Hu XH, Huang GY, Pa M, Li X, Wu L, Liu F, Jia B, and Li GP. Multidetector CT angiography and 3D reconstruction in young children with coarctation of the aorta. *Pediatr Cardiol*. 2008;29:726-31.
150. Yang DH, Goo HW, Seo DM, Yun TJ, Park JJ, Park IS, Ko JK, and Kim YH. Multislice CT angiography of interrupted aortic arch. *Pediatr Radiol*. 2008;38:89-100.
151. Hellinger JC, Daubert M, Lee EY, and Epelman M. Congenital thoracic vascular anomalies: evaluation with state-of-the-art MR imaging and MDCT. *Radiol Clin North Am*. 2011;49:969-96.
152. Siegel MJ. Multiplanar and three-dimensional multi-detector row CT of thoracic vessels and airways in the pediatric population. *Radiology*. 2003;229:641-50.

153. Oguz B, Haliloglu M, and Karcaaltincaba M. Paediatric multidetector CT angiography: spectrum of congenital thoracic vascular anomalies. *Br J Radiol.* 2007;80:376-83.
154. Fruh S, Knirsch W, Dodge-Khatami A, Dave H, Pretre R, and Kretschmar O. Comparison of surgical and interventional therapy of native and recurrent aortic coarctation regarding different age groups during childhood. *Eur J Cardiothorac Surg.* 2011;39:898-904.
155. Becker C, Soppa C, Fink U, Haubner M, Muller-Lisse U, Englmeier KH, Buhlmeyer K, and Reiser M. Spiral CT angiography and 3D reconstruction in patients with aortic coarctation. *Eur Radiol.* 1997;7:1473-7.
156. Nietlispach F, Leipsic J, Wijesinghe N, Webb JG, and Carere RG. First-in-man use of a tapered endovascular stent graft for treatment of aneurysm after coarctation repair. *Catheter Cardiovasc Interv.* 2010;76:1035-40.
157. Chakrabarti S, Kenny D, Morgan G, Curtis SL, Hamilton MC, Wilde P, Tometzki AJ, Turner MS, and Martin RP. Balloon expandable stent implantation for native and recurrent coarctation of the aorta--prospective computed tomography assessment of stent integrity, aneurysm formation and stenosis relief. *Heart.* 2010;96:1212-6.
158. Kutty S, Greenberg RK, Fletcher S, Svensson LG, and Latson LA. Endovascular stent grafts for large thoracic aneurysms after coarctation repair. *Ann Thorac Surg.* 2008;85:1332-8.
159. Brown ML, Burkhart HM, Connolly HM, Dearani JA, Cetta F, Li Z, Oliver WC, Warnes CA, and Schaff HV. Coarctation of the aorta: lifelong surveillance is mandatory following surgical repair. *J Am Coll Cardiol.* 2013;62:1020-5.
160. Lee EY, and Siegel MJ. MDCT of tracheobronchial narrowing in pediatric patients. *J Thorac Imaging.* 2007;22:300-9.
161. Lee EY, Zurakowski D, Waltz DA, Mason KP, Riaz F, Ralph A, and Boiselle PM. MDCT evaluation of the prevalence of tracheomalacia in children with mediastinal aortic vascular anomalies. *J Thorac Imaging.* 2008;23:258-65.
162. Jhang WK, Park JJ, Seo DM, Goo HW, and Gwak M. Perioperative evaluation of airways in patients with arch obstruction and intracardiac defects. *Ann Thorac Surg.* 2008;85:1753-8.
163. An HS, Choi EY, Kwon BS, Kim GB, Bae EJ, Noh CI, Choi JY, Kim WH, Lee JR, Kim YJ, et al. Airway compression in children with congenital heart disease evaluated using computed tomography. *Ann Thorac Surg.* 2013;96:2192-7.
164. Zhong YM, Jaffe RB, Liu JF, Sun AM, Gao W, Wang Q, Zhu M, Qiu HS, and Berdon WE. Multi-slice computed tomography assessment of bronchial compression with absent pulmonary valve. *Pediatr Radiol.* 2014;44:803-9.

165. Lee KS, and Boiselle PM. Update on multidetector computed tomography imaging of the airways. *J Thorac Imaging*. 2010;25:112-24.
166. Watanabe N, Hayabuchi Y, Inoue M, Sakata M, Nabo MM, Nakagawa R, Saijo T, and Kagami S. Tracheal compression due to an elongated aortic arch in patients with congenital heart disease: evaluation using multidetector-row CT. *Pediatr Radiol*. 2009;39:1048-53.
167. Jiao H, Xu Z, Wu L, Cheng Z, Ji X, Zhong H, and Meng C. Detection of airway anomalies in pediatric patients with cardiovascular anomalies with low dose prospective ECG-gated dual-source CT. *PLoS One*. 2013;8:e82826.
168. Hernanz-Schulman M. Vascular rings: a practical approach to imaging diagnosis. *Pediatr Radiol*. 2005;35:961-79.
169. Jang WS, Kim WH, Choi K, Nam J, Kim JT, Lee JR, Kim YJ, and Kim GB. Aortopexy With Preoperative Computed Tomography and Intraoperative Bronchoscopy for Patients With Central Airway Obstruction After Surgery for Congenital Heart Disease: Postoperative Computed Tomography Results and Clinical Outcomes. *Pediatric cardiology*. 2014.
170. Prasad R, Srivastava GN, Mishra OP, and Singh UK. Unilateral pulmonary artery agenesis with vertebral anomaly. *BMJ Case Rep*. 2013.
171. Rousou AJ, Tetenta S, and Boffa DJ. Pulmonary artery agenesis and Kommerell's diverticulum presenting with hemoptysis. *Eur J Cardiothorac Surg*. 2009;35:370-2.
172. Balci TA, Koc ZP, Kirkil G, and Poyraz AK. Isolated left pulmonary artery agenesis: a case report. *Mol Imaging Radionucl Ther*. 2012;21:80-3.
173. Camera L, Fusari M, Calabrese M, Sirignano C, Catalano L, Santoro A, Galderisi M, and Salvatore M. Isolated unilateral absence of pulmonary artery mimicking chronic pulmonary embolism at chest X-ray: multidetector-row CT angiographic findings. *Clin Imaging*. 2012;36:845-9.
174. Battal B, Karaman B, Akgun V, Bozlar U, and Ors F. Images in vascular medicine: agenesis of the left pulmonary artery accompanied by right aortic arch anomaly: CT angiography findings of a case. *Vasc Med*. 2012;17:123-4.
175. Singhi AK, Nicholson I, Francis E, Kumar RK, and Hawker R. Anomalous systemic arterial supply to normal basal segment of the left lung. *Heart Lung Circ*. 2011;20:357-61.
176. Oguz B, Alan S, Ozcelik U, and Haliloglu M. Horseshoe lung associated with left-lung hypoplasia, left pulmonary artery sling and bilateral agenesis of upper lobe bronchi. *Pediatr Radiol*. 2009;39:1002-5.

177. Haest RJ, van den Berg CJ, Goei R, and Baur LH. Scimitar syndrome; an unusual congenital abnormality occasionally seen in adults. *Int J Cardiovasc Imaging*. 2006;22:565-8.
178. Miyake H, Hori Y, Takeoka H, Takuma M, Kawagoe T, and Mori H. Systemic arterial supply to normal basal segments of the left lung: characteristic features on chest radiography and CT. *AJR Am J Roentgenol*. 1998;171:387-92.
179. Yu H, Li HM, Liu SY, and Xiao XS. Diagnosis of arterial sequestration using multidetector CT angiography. *Eur J Radiol*. 2010;76:274-8.
180. Saeed A, Kazmierski M, Khan A, McShane D, Gomez A, and Aslam A. Congenital lung lesions: preoperative three-dimensional reconstructed CT scan as the definitive investigation and surgical management. *Eur J Pediatr Surg*. 2013;23:53-6.
181. Yue SW, Guo H, Zhang YG, Gao JB, Ma XX, and Ding PX. The clinical value of computer tomographic angiography for the diagnosis and therapeutic planning of patients with pulmonary sequestration. *Eur J Cardiothorac Surg*. 2013;43:946-51.
182. Ko SF, Liang CD, Yip HK, Huang CC, Ng SH, Huang CF, and Chen MC. Amplatzer septal occluder closure of atrial septal defect: evaluation of transthoracic echocardiography, cardiac CT, and transesophageal echocardiography. *AJR Am J Roentgenol*. 2009;193:1522-9.
183. Zaidi AN, Cheatham JP, Raman SV, and Cook SC. Multislice computed tomographic findings in symptomatic patients after amplatzer septal occluder device implantation. *J Interv Cardiol*. 2009;22:92-7.
184. Knickelbine T, Lesser JR, Haas TS, Brandenburg ER, Gleason-Han BK, Flygenring B, Longe TF, Schwartz RS, and Maron BJ. Identification of unexpected nonatherosclerotic cardiovascular disease with coronary CT angiography. *JACC Cardiovasc Imaging*. 2009;2:1085-92.
185. Myers PO, del Nido PJ, Marx GR, Emani S, Mayer JE, Jr., Pigula FA, and Baird CW. Improving left ventricular outflow tract obstruction repair in common atrioventricular canal defects. *Ann Thorac Surg*. 2012;94:599-605.
186. McGrath LB, Kirklin JW, Soto B, and Barger LM, Jr. Secondary left atrioventricular valve replacement in atrioventricular septal (AV canal) defect: a method to avoid left ventricular outflow tract obstruction. *J Thorac Cardiovasc Surg*. 1985;89:632-5.
187. Douglas WI, and Doshi U. A Novel Technique for Repair of Complete Atrioventricular Canal Defect: The Central Patch Technique. *World J Pediatr Congenit Heart Surg*. 2014;5:434-9.
188. Pacifico AD, Ricchi A, Barger LM, Jr., Colvin EC, Kirklin JW, and Kirklin JK. Corrective repair of complete atrioventricular canal defects and major associated cardiac anomalies. *Ann Thorac Surg*. 1988;46:645-51.

189. Vastel-Amzallag C, Le Bret E, Paul JF, Lambert V, Rohnean A, El Fassy E, and Sigal-Cinquandre A. Diagnostic accuracy of dual-source multislice computed tomographic analysis for the preoperative detection of coronary artery anomalies in 100 patients with tetralogy of Fallot. *J Thorac Cardiovasc Surg.* 2011;142:120-6.
190. Lin MT, Wang JK, Chen YS, Lee WJ, Chiu HH, Chen CA, Chiu SN, Wu ET, Lu CW, Huang SC, et al. Detection of pulmonary arterial morphology in tetralogy of Fallot with pulmonary atresia by computed tomography: 12 years of experience. *Eur J Pediatr.* 2012;171:579-86.
191. Westra SJ, Hill JA, Alejos JC, Galindo A, Boechat MI, and Laks H. Three-dimensional helical CT of pulmonary arteries in infants and children with congenital heart disease. *AJR Am J Roentgenol.* 1999;173:109-15.
192. Westra SJ, Hurteau J, Galindo A, McNitt-Gray MF, Boechat MI, and Laks H. Cardiac electron-beam CT in children undergoing surgical repair for pulmonary atresia. *Radiology.* 1999;213:502-12.
193. Rajeshkannan R, Moorthy S, Sreekumar KP, Ramachandran PV, Kumar RK, and Remadevi KS. Role of 64-MDCT in evaluation of pulmonary atresia with ventricular septal defect. *AJR Am J Roentgenol.* 2010;194:110-8.
194. Maeda E, Akahane M, Kato N, Hayashi N, Koga H, Yamada H, Kato H, and Ohtomo K. Assessment of major aortopulmonary collateral arteries with multidetector-row computed tomography. *Radiat Med.* 2006;24:378-83.
195. Hayabuchi Y, Inoue M, Watanabe N, Sakata M, Nabo MM, Kitagawa T, Kitaichi T, and Kagami S. Assessment of systemic-pulmonary collateral arteries in children with cyanotic congenital heart disease using multidetector-row computed tomography: comparison with conventional angiography. *Int J Cardiol.* 2010;138:266-71.
196. Wang XM, Wu LB, Sun C, Liu C, Chao BT, Han B, Zhang YT, Chen HS, and Li ZJ. Clinical application of 64-slice spiral CT in the diagnosis of the Tetralogy of Fallot. *Eur J Radiol.* 2007;64:296-301.
197. Valente AM, Cook S, Festa P, Ko HH, Krishnamurthy R, Taylor AM, Warnes CA, Kreutzer J, and Geva T. Multimodality imaging guidelines for patients with repaired tetralogy of fallot: a report from the american society of echocardiography: developed in collaboration with the society for cardiovascular magnetic resonance and the society for pediatric radiology. *J Am Soc Echocardiogr.* 2014;27:111-41.
198. Meinel FG, Huda W, Schoepf UJ, Rao AG, Cho YJ, Baker GH, and Hlavacek AM. Diagnostic accuracy of CT angiography in infants with tetralogy of Fallot with pulmonary atresia and major aortopulmonary collateral arteries. *J Cardiovasc Comput Tomogr.* 2013;7:367-75.

199. Greil GF, Schoebinger M, Kuettner A, Schaefer JF, Dammann F, Claussen CD, Hofbeck M, Meinzer HP, and Sieverding L. Imaging of aortopulmonary collateral arteries with high-resolution multidetector CT. *Pediatr Radiol.* 2006;36:502-9.
200. Chalard A, Sanchez I, Gouton M, Henaine R, Salami FA, Ninet J, Douek PC, Di Filippo S, and Bousset L. Effect of pulmonary valve replacement on left ventricular function in patients with tetralogy of Fallot. *Am J Cardiol.* 2012;110:1828-35.
201. Broberg CS, Aboulhosn J, Mongeon FP, Kay J, Valente AM, Khairy P, Earing MG, Opatowsky AR, Lui G, Gersony DR, et al. Prevalence of left ventricular systolic dysfunction in adults with repaired tetralogy of fallot. *Am J Cardiol.* 2011;107:1215-20.
202. Tobler D, Crean AM, Redington AN, Van Arsdell GS, Caldarone CA, Nanthakumar K, Stambach D, Dos L, Wintersperger BJ, Oechslin EN, et al. The left heart after pulmonary valve replacement in adults late after tetralogy of Fallot repair. *Int J Cardiol.* 2012;160:165-70.
203. Ferraz Cavalcanti PE, Sa MP, Santos CA, Esmeraldo IM, de Escobar RR, de Menezes AM, de Azevedo OM, Jr., de Vasconcelos Silva FP, Lins RF, and Lima Rde C. Pulmonary valve replacement after operative repair of tetralogy of Fallot: meta-analysis and meta-regression of 3,118 patients from 48 studies. *J Am Coll Cardiol.* 2013;62:2227-43.
204. Geva T. Repaired tetralogy of Fallot: the roles of cardiovascular magnetic resonance in evaluating pathophysiology and for pulmonary valve replacement decision support. *J Cardiovasc Magn Reson.* 2011;13:9.
205. Geva T. Indications for pulmonary valve replacement in repaired tetralogy of fallot: the quest continues. *Circulation.* 2013;128:1855-7.
206. Khairy P, Aboulhosn J, Gurvitz MZ, Opatowsky AR, Mongeon FP, Kay J, Valente AM, Earing MG, Lui G, Gersony DR, et al. Arrhythmia burden in adults with surgically repaired tetralogy of Fallot: a multi-institutional study. *Circulation.* 2010;122:868-75.
207. Le Gloan L, and Khairy P. Management of arrhythmias in patients with tetralogy of Fallot. *Curr Opin Cardiol.* 2011;26:60-5.
208. Khairy P, Dore A, Poirier N, Marcotte F, Ibrahim R, Mongeon FP, and Mercier LA. Risk stratification in surgically repaired tetralogy of Fallot. *Expert Rev Cardiovasc Ther.* 2009;7:755-62.
209. Raman SV, Cook SC, McCarthy B, and Ferketich AK. Usefulness of multidetector row computed tomography to quantify right ventricular size and function in adults with either tetralogy of Fallot or transposition of the great arteries. *Am J Cardiol.* 2005;95:683-6.
210. Brodoefel H, Kramer U, Reimann A, Burgstahler C, Schroeder S, Kopp A, and Heuschmid M. Dual-source CT with improved temporal resolution in assessment of left ventricular function: a pilot study. *AJR Am J Roentgenol.* 2007;189:1064-70.

211. Saremi F, Ho SY, Cabrera JA, and Sanchez-Quintana D. Right ventricular outflow tract imaging with CT and MRI: Part 2, Function. *AJR Am J Roentgenol.* 2013;200:W51-61.
212. Takx RA, Moscariello A, Schoepf UJ, Barraza JM, Jr., Nance JW, Jr., Bastarrika G, Das M, Meyer M, Wildberger JE, Schoenberg SO, et al. Quantification of left and right ventricular function and myocardial mass: comparison of low-radiation dose 2nd generation dual-source CT and cardiac MRI. *Eur J Radiol.* 2012;81:e598-604.
213. Yamasaki Y, Nagao M, Yamamura K, Yonezawa M, Matsuo Y, Kawanami S, Kamitani T, Higuchi K, Sakamoto I, Shiokawa Y, et al. Quantitative assessment of right ventricular function and pulmonary regurgitation in surgically repaired tetralogy of Fallot using 256-slice CT: comparison with 3-Tesla MRI. *Eur Radiol.* 2014;24:3289-99.
214. Momenah TS, El Oakley R, Al Najashi K, Khoshhal S, Al Qethamy H, and Bonhoeffer P. Extended application of percutaneous pulmonary valve implantation. *J Am Coll Cardiol.* 2009;53:1859-63.
215. Meadows JJ, Moore PM, Berman DP, Cheatham JP, Cheatham SL, Porras D, Gillespie MJ, Rome JJ, Zahn EM, and McElhinney DB. Use and performance of the Melody Transcatheter Pulmonary Valve in native and postsurgical, nonconduit right ventricular outflow tracts. *Circ Cardiovasc Interv.* 2014;7:374-80.
216. Berman DP, McElhinney DB, Vincent JA, Hellenbrand WE, and Zahn EM. Feasibility and short-term outcomes of percutaneous transcatheter pulmonary valve replacement in small (<30 kg) children with dysfunctional right ventricular outflow tract conduits. *Circ Cardiovasc Interv.* 2014;7:142-8.
217. Kalfa DM, Serraf AE, Ly M, Le Bret E, Roussin R, and Belli E. Tetralogy of Fallot with an abnormal coronary artery: surgical options and prognostic factors. *Eur J Cardiothorac Surg.* 2012;42:e34-9.
218. Morray BH, McElhinney DB, Cheatham JP, Zahn EM, Berman DP, Sullivan PM, Lock JE, and Jones TK. Risk of coronary artery compression among patients referred for transcatheter pulmonary valve implantation: a multicenter experience. *Circ Cardiovasc Interv.* 2013;6:535-42.
219. McElhinney DB, Cheatham JP, Jones TK, Lock JE, Vincent JA, Zahn EM, and Hellenbrand WE. Stent fracture, valve dysfunction, and right ventricular outflow tract reintervention after transcatheter pulmonary valve implantation: patient-related and procedural risk factors in the US Melody Valve Trial. *Circ Cardiovasc Interv.* 2011;4:602-14.
220. McElhinney DB, Hellenbrand WE, Zahn EM, Jones TK, Cheatham JP, Lock JE, and Vincent JA. Short- and medium-term outcomes after transcatheter pulmonary valve placement in the expanded multicenter US melody valve trial. *Circulation.* 2010;122:507-16.

221. Mongeon FP, Gurvitz MZ, Broberg CS, Aboulhosn J, Opotowsky AR, Kay JD, Valente AM, Earing MG, Lui GK, Fernandes SM, et al. Aortic root dilatation in adults with surgically repaired tetralogy of fallot: a multicenter cross-sectional study. *Circulation*. 2013;127:172-9.
222. Warnes CA. Adult congenital heart disease importance of the right ventricle. *J Am Coll Cardiol*. 2009;54:1903-10.
223. Khairy P, Van Hare GF, Balaji S, Berul CI, Cecchin F, Cohen MI, Daniels CJ, Deal BJ, Dearani JA, Groot N, et al. PACES/HRS Expert Consensus Statement on the Recognition and Management of Arrhythmias in Adult Congenital Heart Disease: developed in partnership between the Pediatric and Congenital Electrophysiology Society (PACES) and the Heart Rhythm Society (HRS). Endorsed by the governing bodies of PACES, HRS, the American College of Cardiology (ACC), the American Heart Association (AHA), the European Heart Rhythm Association (EHRA), the Canadian Heart Rhythm Society (CHRS), and the International Society for Adult Congenital Heart Disease (ISACHD). *Heart Rhythm*. 2014;11:e102-65.
224. Gelatt M, Hamilton RM, McCrindle BW, Connelly M, Davis A, Harris L, Gow RM, Williams WG, Trusler GA, and Freedom RM. Arrhythmia and mortality after the Mustard procedure: a 30-year single-center experience. *J Am Coll Cardiol*. 1997;29:194-201.
225. Warnes CA. Transposition of the great arteries. *Circulation*. 2006;114:2699-709.
226. Patel S, Shah D, Chintala K, and Karpawich PP. Atrial baffle problems following the Mustard operation in children and young adults with dextro-transposition of the great arteries: the need for improved clinical detection in the current era. *Congenit Heart Dis*. 2011;6:466-74.
227. Khairy P, Landzberg MJ, Lambert J, and O'Donnell CP. Long-term outcomes after the atrial switch for surgical correction of transposition: a meta-analysis comparing the Mustard and Senning procedures. *Cardiol Young*. 2004;14:284-92.
228. Horer J, Karl E, Theodoratou G, Schreiber C, Cleuziou J, Prodan Z, Vogt M, and Lange R. Incidence and results of reoperations following the Senning operation: 27 years of follow-up in 314 patients at a single center. *Eur J Cardiothorac Surg*. 2008;33:1061-7; discussion 7-8.
229. Gutberlet M, Hoffmann J, Kunzel E, Fleischer A, Sarikouch S, Beerbaum P, Lehmkuhl L, Andres C, Lurz P, Kostelka M, et al. [Preoperative and postoperative imaging in patients with transposition of the great arteries]. *Radiologe*. 2011;51:15-22.
230. Kaemmerer H, Bahlmann M, Prokop M, Schirg E, Luhmer I, and Kallfelz HC. [Evaluation of congenital vena cava anomalies and acquired vena cava obstructions after atrial switch operation using spiral computerized tomography and 3-dimensional reconstruction]. *Z Kardiol*. 1997;86:669-75.

231. Cook SC, McCarthy M, Daniels CJ, Cheatham JP, and Raman SV. Usefulness of multislice computed tomography angiography to evaluate intravascular stents and transcatheter occlusion devices in patients with d-transposition of the great arteries after mustard repair. *Am J Cardiol.* 2004;94:967-9.
232. Han BK, and Lesser JR. CT imaging in congenital heart disease: an approach to imaging and interpreting complex lesions after surgical intervention for tetralogy of Fallot, transposition of the great arteries, and single ventricle heart disease. *J Cardiovasc Comput Tomogr.* 2013;7:338-53.
233. Niazi I, Dhala A, Choudhuri I, Sra J, Akhtar M, and Tajik AJ. Cardiac Resynchronization Therapy in Patients with Challenging Anatomy Due to Venous Anomalies or Adult Congenital Heart Disease. *Pacing Clin Electrophysiol.* 2014;37:1181-8.
234. Ruckdeschel ES, Quaife R, Lewkowicz L, Kay J, Sauer WH, Collins KK, and Nguyen DT. Preprocedural imaging in patients with transposition of the great arteries facilitates placement of cardiac resynchronization therapy leads. *Pacing Clin Electrophysiol.* 2014;37:546-53.
235. Jatene AD, Fontes VF, Paulista PP, de Souza LC, Neger F, Galantier M, and Souza JE. Successful anatomic correction of transposition of the great vessels. A preliminary report. *Arq Bras Cardiol.* 1975;28:461-64.
236. Pasquali SK, Hasselblad V, Li JS, Kong DF, and Sanders SP. Coronary artery pattern and outcome of arterial switch operation for transposition of the great arteries: a meta-analysis. *Circulation.* 2002;106:2575-80.
237. Horer J, Schreiber C, Cleuziou J, Vogt M, Prodan Z, Busch R, Holper K, and Lange R. Improvement in long-term survival after hospital discharge but not in freedom from reoperation after the change from atrial to arterial switch for transposition of the great arteries. *J Thorac Cardiovasc Surg.* 2009;137:347-54.
238. Tobler D, Williams WG, Jegatheeswaran A, Van Arsdell GS, McCrindle BW, Greutmann M, Oechslin EN, and Silversides CK. Cardiac outcomes in young adult survivors of the arterial switch operation for transposition of the great arteries. *J Am Coll Cardiol.* 2010;56:58-64.
239. Villafane J, Lantin-Hermoso MR, Bhatt AB, Tweddell JS, Geva T, Nathan M, Elliott MJ, Vetter VL, Paridon SM, Kochilas L, et al. D-Transposition of the Great Arteries: The Current Era of the Arterial Switch Operation. *J Am Coll Cardiol.* 2014;64:498-511.
240. Khairy P, Clair M, Fernandes SM, Blume ED, Powell AJ, Newburger JW, Landzberg MJ, and Mayer JE, Jr. Cardiovascular outcomes after the arterial switch operation for D-transposition of the great arteries. *Circulation.* 2013;127:331-9.
241. Angeli E, Formigari R, Pace Napoleone C, Oppido G, Ragni L, Picchio FM, and Gargiulo G. Long-term coronary artery outcome after arterial switch operation for transposition of the great arteries. *Eur J Cardiothorac Surg.* 2010;38:714-20.

242. Bonnet D, Bonhoeffer P, Piechaud JF, Aggoun Y, Sidi D, Planche C, and Kachaner J. Long-term fate of the coronary arteries after the arterial switch operation in newborns with transposition of the great arteries. *Heart*. 1996;76:274-9.
243. Ou P, Khraiche D, Celermajer DS, Agnoletti G, Le Quan Sang KH, Thalabard JC, Quintin M, Raisky O, Vouhe P, Sidi D, et al. Mechanisms of coronary complications after the arterial switch for transposition of the great arteries. *J Thorac Cardiovasc Surg*. 2013;145:1263-9.
244. Veltman CE, Beeres SL, Kalkman DN, Kelder TP, Kies P, Vliegen HW, Hazekamp MG, Delgado V, Kroft LJ, van der Wall EE, et al. Variation in coronary anatomy in adult patients late after arterial switch operation: a computed tomography coronary angiography study. *Ann Thorac Surg*. 2013;96:1390-7.
245. Ou P, Celermajer DS, Marini D, Agnoletti G, Vouhe P, Brunelle F, Le Quan Sang KH, Thalabard JC, Sidi D, and Bonnet D. Safety and accuracy of 64-slice computed tomography coronary angiography in children after the arterial switch operation for transposition of the great arteries. *JACC Cardiovasc Imaging*. 2008;1:331-9.
246. Ou P, Mousseaux E, Azarine A, Dupont P, Agnoletti G, Vouhe P, Sidi D, and Bonnet D. Detection of coronary complications after the arterial switch operation for transposition of the great arteries: first experience with multislice computed tomography in children. *J Thorac Cardiovasc Surg*. 2006;131:639-43.
247. Jemmali M, Marini D, Calcagni G, Brunelle F, Sidi D, Bonnet D, and Ou P. Pediatric coronary artery bypass after arterial switch operation: noninvasive evaluation with ECG-gated 64-slice CT in routine practice. *Ann Thorac Surg*. 2007;84:1398-9.
248. Marini D, Defilippi C, and Agnoletti G. Left coronary artery stenosis with post-stenotic aneurysm after arterial switch operation before and after coronary revascularisation surgery. *Cardiol Young*. 2011;21:456-7.
249. Hazekamp MG, Gomez AA, Koolbergen DR, Hraska V, Metras DR, Mattila IP, Daenen W, Berggren HE, Rubay JE, Stellin G, et al. Surgery for transposition of the great arteries, ventricular septal defect and left ventricular outflow tract obstruction: European Congenital Heart Surgeons Association multicentre study. *Eur J Cardiothorac Surg*. 2010;38:699-706.
250. Lee JR, Lim HG, Kim YJ, Rho JR, Bae EJ, Noh CI, Yun YS, and Ahn C. Repair of transposition of the great arteries, ventricular septal defect and left ventricular outflow tract obstruction. *Eur J Cardiothorac Surg*. 2004;25:735-41.
251. Williams WG, McCrindle BW, Ashburn DA, Jonas RA, Mavroudis C, Blackstone EH, and Congenital Heart Surgeon's S. Outcomes of 829 neonates with complete transposition of the great arteries 12-17 years after repair. *Eur J Cardiothorac Surg*. 2003;24:1-9; discussion -10.

252. Nikaidoh H. Aortic translocation and biventricular outflow tract reconstruction. A new surgical repair for transposition of the great arteries associated with ventricular septal defect and pulmonary stenosis. *J Thorac Cardiovasc Surg.* 1984;88:365-72.
253. Yeh T, Jr., Ramaciotti C, Leonard SR, Roy L, and Nikaidoh H. The aortic translocation (Nikaidoh) procedure: midterm results superior to the Rastelli procedure. *J Thorac Cardiovasc Surg.* 2007;133:461-9.
254. Hu SS, Liu ZG, Li SJ, Shen XD, Wang X, Liu JP, Yan FX, Wang LQ, and Li YQ. Strategy for biventricular outflow tract reconstruction: Rastelli, REV, or Nikaidoh procedure? *J Thorac Cardiovasc Surg.* 2008;135:331-8.
255. Bullock-Palmer RP, and Rohen A. Congenitally corrected transposition of the great arteries (CCTGA) initially presenting in the sixth decade. *Echocardiography.* 2009;26:1118-20.
256. Schwab JO, Ehlgren A, and Sommer T. Congenitally corrected transposition of the great arteries in a 70-year-old woman diagnosed using single-detector helical CT. *AJR Am J Roentgenol.* 2003;181:598.
257. Dupont MV, Dragean CA, and Coche EE. Right ventricle function assessment by MDCT. *AJR Am J Roentgenol.* 2011;196:77-86.
258. Takasugi JE, Godwin JD, and Chen JT. CT in congenitally-corrected transposition of the great vessels. *Comput Radiol.* 1987;11:215-21.
259. Chen SJ, Li YW, Wang JK, Chiu IS, Su CT, Hsu JC, and Lue HC. Three-dimensional reconstruction of abnormal ventriculoarterial relationship by electron beam CT. *J Comput Assist Tomogr.* 1998;22:560-8.
260. Shin'oka T, Kurosawa H, Imai Y, Aoki M, Ishiyama M, Sakamoto T, Miyamoto S, Hobo K, and Ichihara Y. Outcomes of definitive surgical repair for congenitally corrected transposition of the great arteries or double outlet right ventricle with discordant atrioventricular connections: risk analyses in 189 patients. *J Thorac Cardiovasc Surg.* 2007;133:1318-28, 28 e1-4.
261. Lee TM, Aiyagari R, Hirsch JC, Ohye RG, Bove EL, and Devaney EJ. Risk factor analysis for second-stage palliation of single ventricle anatomy. *Ann Thorac Surg.* 2012;93:614-8; discussion 9.
262. Anderson PA, Sleeper LA, Mahony L, Colan SD, Atz AM, Breitbart RE, Gersony WM, Gallagher D, Geva T, Margossian R, et al. Contemporary outcomes after the Fontan procedure: a Pediatric Heart Network multicenter study. *J Am Coll Cardiol.* 2008;52:85-98.
263. Iyengar AJ, Winlaw DS, Galati JC, Wheaton GR, Gentles TL, Grigg LE, Justo RN, Radford DJ, Weintraub RG, Bullock A, et al. The extracardiac conduit Fontan procedure

- in Australia and New Zealand: hypoplastic left heart syndrome predicts worse early and late outcomes. *Eur J Cardiothorac Surg.* 2014;46:465-73.
264. Feinstein JA, Benson DW, Dubin AM, Cohen MS, Maxey DM, Mahle WT, Pahl E, Villafane J, Bhatt AB, Peng LF, et al. Hypoplastic left heart syndrome: current considerations and expectations. *J Am Coll Cardiol.* 2012;59:S1-42.
265. Jacobs JP, and Maruszewski B. Functionally univentricular heart and the fontan operation: lessons learned about patterns of practice and outcomes from the congenital heart surgery databases of the European association for cardio-thoracic surgery and the society of thoracic surgeons. *World J Pediatr Congenit Heart Surg.* 2013;4:349-55.
266. Downing TE, McDonnell A, Zhu X, Dori Y, Gillespie MJ, Rome JJ, and Glatz AC. Cumulative Medical Radiation Exposure Throughout Staged Palliation of Single Ventricle Congenital Heart Disease. *Pediatr Cardiol.* Jan;36(1):190-5.
267. Hoashi T, Kagisaki K, Oda T, Kitano M, Kurosaki K, Shiraishi I, Yagihara T, and Ichikawa H. Long-term results of treatments for functional single ventricle associated with extracardiac type total anomalous pulmonary venous connection. *Eur J Cardiothorac Surg.* 2013;43:965-70.
268. Padalino MA, Cavalli G, De Franceschi M, Mancuso D, Maschietto N, Vida V, Milanese O, and Stellin G. Surgical Outcomes of Total Anomalous Pulmonary Venous Connection Repair: A 22-Year Experience. *Journal of cardiac surgery.* 2014.
269. Kelle AM, Backer CL, Gossett JG, Kaushal S, and Mavroudis C. Total anomalous pulmonary venous connection: results of surgical repair of 100 patients at a single institution. *J Thorac Cardiovasc Surg.* 2010;139:1387-94 e3.
270. Watanabe M, Aoki M, and Fujiwara T. Thrombotic occlusion of Blalock-Taussig shunt in a patient with unnoticed protein C deficiency. *Gen Thorac Cardiovasc Surg.* 2008;56:544-6.
271. Piggott KD, Nykanen DG, and Smith S. Computed tomography angiography successfully used to diagnose postoperative systemic-pulmonary artery shunt narrowing. *Case Rep Cardiol.* 2011;2011:802643.
272. Han BK, Vezmar M, Lesser JR, Michalak G, Grant K, Dassenko D, Maresh J, and Overman DM. Selective use of cardiac computed tomography angiography: An alternative diagnostic modality before second-stage single ventricle palliation. *The Journal of thoracic and cardiovascular surgery.* 2014. Oct;148(4):1548-54
273. Brown DW, Gauvreau K, Powell AJ, Lang P, del Nido PJ, Odegard KC, and Geva T. Cardiac magnetic resonance versus routine cardiac catheterization before bidirectional Glenn anastomosis: long-term follow-up of a prospective randomized trial. *J Thorac Cardiovasc Surg.* 2013;146:1172-8.

274. Fogel MA, Pawlowski TW, Whitehead KK, Harris MA, Keller MS, Glatz AC, Zhu W, Shore D, Diaz LK, and Rome JJ. Cardiac Magnetic Resonance and the Need for Routine Cardiac Catheterization in Single Ventricle Patients Prior to Fontan: A Comparison of 3 Groups: Pre-Fontan CMR Versus Cath Evaluation. *J Am Coll Cardiol*. 2012;60:1094-102.
275. Fogel MA. Is routine cardiac catheterization necessary in the management of patients with single ventricles across staged Fontan reconstruction? No! *Pediatr Cardiol*. 2005;26:154-8.
276. Gottlieb EA, and Andropoulos DB. Anesthesia for the patient with congenital heart disease presenting for noncardiac surgery. *Curr Opin Anaesthesiol*. 2013;26:318-26.
277. Ramamoorthy C, Haberkern CM, Bhananker SM, Domino KB, Posner KL, Campos JS, and Morray JP. Anesthesia-related cardiac arrest in children with heart disease: data from the Pediatric Perioperative Cardiac Arrest (POCA) registry. *Anesth Analg*. 2010;110:1376-82.
278. Rabbitts JA, Groenewald CB, Mauermann WJ, Barbara DW, Burkhart HM, Warnes CA, Oliver WC, Jr., and Flick RP. Outcomes of general anesthesia for noncardiac surgery in a series of patients with Fontan palliation. *Paediatr Anaesth*. 2013;23:180-7.
279. Chandran A, Bleiweis MS, and Fricker FJ. Evaluating the extracardiac Fontan conduit by multislice computed tomography: an emerging modality. *Cardiology in the young*. 2009;19:204-5.
280. Choi BW, Park YH, Lee JK, Kim DJ, Kim MJ, and Choe KO. Patency of cavopulmonary connection studied by single phase electron beam computed tomography. *Int J Cardiovasc Imaging*. 2003;19:447-55.
281. Glockler M, Koch A, Halbfass J, Greim V, Ruffer A, Cesnjevar R, Achenbach S, and Dittrich S. Assessment of cavopulmonary connections by advanced imaging: value of flat-detector computed tomography. *Cardiol Young*. 2012:1-9.
282. Goo HW, Jhang WK, Kim YH, Ko JK, Park IS, Park JJ, Yun TJ, and Seo DM. CT findings of plastic bronchitis in children after a Fontan operation. *Pediatr Radiol*. 2008;38:989-93.
283. Park EA, Lee W, Chung SY, Yin YH, Chung JW, and Park JH. Optimal scan timing and intravenous route for contrast-enhanced computed tomography in patients after Fontan operation. *J Comput Assist Tomogr*. 2010;34:75-81.
284. Ji X, Zhao B, Cheng Z, Si B, Wang Z, Duan Y, Nie P, Li H, Yang S, Jiao H, et al. Low-dose prospectively electrocardiogram-gated axial dual-source CT angiography in patients with pulsatile bilateral bidirectional Glenn Shunt: an alternative noninvasive method for postoperative morphological estimation. *PLoS One*. 2014;9:e94425.

285. Prabhu SP, Mahmood S, Sena L, and Lee EY. MDCT evaluation of pulmonary embolism in children and young adults following a lateral tunnel Fontan procedure: optimizing contrast-enhancement techniques. *Pediatric radiology*. 2009;39:938-44.
286. Fredenburg TB, Johnson TR, and Cohen MD. The Fontan procedure: anatomy, complications, and manifestations of failure. *Radiographics*. 2011;31:453-63.
287. McCrindle BW, Manlihot C, Cochrane A, Roberts R, Hughes M, Szechtman B, Weintraub R, Andrew M, Monagle P, and Fontan Anticoagulation Study G. Factors associated with thrombotic complications after the Fontan procedure: a secondary analysis of a multicenter, randomized trial of primary thromboprophylaxis for 2 years after the Fontan procedure. *J Am Coll Cardiol*. 2013;61:346-53.
288. Kardos M. Detection of right ventricle thrombosis in patient with Ebstein anomaly of tricuspid valve after Fontan procedure by CT. *J Cardiovasc Comput Tomogr*. 2014;8:248-9.
289. Lee SY, Baek JS, Kim GB, Kwon BS, Bae EJ, Noh CI, Choi JY, Lim HK, Kim WH, Lee JR, et al. Clinical significance of thrombosis in an intracardiac blind pouch after a Fontan operation. *Pediatr Cardiol*. 2012;33:42-8.
290. Grewal J, Al Hussein M, Feldstein J, Kiess M, Ellis J, Human D, and Leipsic J. Evaluation of silent thrombus after the Fontan operation. *Congenit Heart Dis*. 2013;8:40-7.
291. Varma C, Warr MR, Hendler AL, Paul NS, Webb GD, and Therrien J. Prevalence of "silent" pulmonary emboli in adults after the Fontan operation. *J Am Coll Cardiol*. 2003;41:2252-8.
292. Singh HR, Forbes TJ, and Humes RA. CT artifact mimicking pulmonary embolism in a patient with single ventricle. *Pediatr Cardiol*. 2008;29:241-2.
293. Prescott-Focht JA, Martinez-Jimenez S, Hurwitz LM, Hoang JK, Christensen JD, Ghoshhajra BB, and Abbara S. Ascending thoracic aorta: postoperative imaging evaluation. *Radiographics*. 2013;33:73-85.
294. Charitos EI, Stierle U, Hanke T, Bechtel M, Sievers HH, and Petersen M. Pulmonary homograft morphology after the Ross procedure: a computed tomography study. *J Heart Valve Dis*. 2011;20:688-94.
295. Shrestha M, Khaladj N, Baraki H, Al Ahmad A, Koigeldiyev N, Pichlmaier M, Haverich A, and Hagl C. Aortic root reoperation: a technical challenge. *J Heart Valve Dis*. 2010;19:177-81.
296. Shikata F, Nagashima M, Higaki T, and Kawachi K. Occlusion of the right coronary artery ostium by an aortic cusp attachment. *Interact Cardiovasc Thorac Surg*. 2010;10:639-41.

297. Cheatham JP. Stenting of coarctation of the aorta. *Catheter Cardiovasc Interv.* 2001;54:112-25.
298. Eichhorn JG, Jourdan C, Hill SL, Raman SV, Cheatham JP, and Long FR. CT of pediatric vascular stents used to treat congenital heart disease. *AJR Am J Roentgenol.* 2008;190:1241-6.
299. Ferandos C, El-Said H, Hamzeh R, and Moore JW. Adverse impact of vascular stent "mass effect" on airways. *Catheter Cardiovasc Interv.* 2009;74:132-6.
300. Hamzeh RK, El-Said HG, and Moore JW. Left main coronary artery compression from right pulmonary artery stenting. *Catheter Cardiovasc Interv.* 2009;73:197-202.
301. Fidler JL, Cheatham JP, Fletcher SE, Martin AB, Kugler JD, Gumbiner CH, and Danford DA. CT angiography of complications in pediatric patients treated with intravascular stents. *AJR Am J Roentgenol.* 2000;174:355-9.
302. Rubin GD, Leipsic J, Joseph Schoepf U, Fleischmann D, and Napel S. CT angiography after 20 years: a transformation in cardiovascular disease characterization continues to advance. *Radiology.* 2014;271:633-52.
303. Wolf F, Leschka S, Loewe C, Homolka P, Plank C, Scherthaner R, Bercaczy D, Goetti R, Lammer J, Friedrich G, et al. Coronary artery stent imaging with 128-slice dual-source CT using high-pitch spiral acquisition in a cardiac phantom: comparison with the sequential and low-pitch spiral mode. *European radiology.* 2010;20:2084-91.
304. Zhao L, Zhang Z, Fan Z, Yang L, and Du J. Prospective versus retrospective ECG gating for dual source CT of the coronary stent: comparison of image quality, accuracy, and radiation dose. *European journal of radiology.* 2011;77:436-42.
305. Wuest W, May MS, Scharf M, Layritz C, Eisentopf J, Ropers D, Pflederer T, Uder M, Achenbach S, and Lell MM. Stent evaluation in low-dose coronary CT angiography: effect of different iterative reconstruction settings. *J Cardiovasc Comput Tomogr.* 2013;7:319-25.
306. Eisentopf J, Achenbach S, Ulzheimer S, Layritz C, Wuest W, May M, Lell M, Ropers D, Klinghammer L, Daniel WG, et al. Low-dose dual-source CT angiography with iterative reconstruction for coronary artery stent evaluation. *JACC Cardiovasc Imaging.* 2013;6:458-65.
307. Oda S, Utsunomiya D, Funama Y, Takaoka H, Katahira K, Honda K, Noda K, Oshima S, and Yamashita Y. Improved coronary in-stent visualization using a combined high-resolution kernel and a hybrid iterative reconstruction technique at 256-slice cardiac CT-Pilot study. *Eur J Radiol.* 2013;82:288-95.
308. Friedman BA, Schoepf UJ, Bastarrika GA, and Hlavacek AM. Computed tomographic angiography of infants with congenital heart disease receiving extracorporeal membrane oxygenation. *Pediatr Cardiol.* 2009;30:1154-6.

309. Acharya D, Singh S, Tallaj JA, Holman WL, George JF, Kirklin JK, and Pamboukian SV. Use of gated cardiac computed tomography angiography in the assessment of left ventricular assist device dysfunction. *ASAIO J.* 2011;57:32-7.
310. Burchill LJ, Mertens L, and Broberg CS. Imaging for the assessment of heart failure in congenital heart disease: ventricular function and beyond. *Heart Fail Clin.* 2014;10:9-22.
311. Rodriguez FH, 3rd, and Marelli AJ. The epidemiology of heart failure in adults with congenital heart disease. *Heart Fail Clin.* 2014;10:1-7.
312. Guo YK, Gao HL, Zhang XC, Wang QL, Yang ZG, and Ma ES. Accuracy and reproducibility of assessing right ventricular function with 64-section multi-detector row CT: comparison with magnetic resonance imaging. *Int J Cardiol.* 2010;139:254-62.
313. Busch S, Johnson TR, Wintersperger BJ, Minaifar N, Bhargava A, Rist C, Reiser MF, Becker C, and Nikolaou K. Quantitative assessment of left ventricular function with dual-source CT in comparison to cardiac magnetic resonance imaging: initial findings. *Eur Radiol.* 2008;18:570-5.
314. Yamamuro M, Tadamura E, Kubo S, Toyoda H, Nishina T, Ohba M, Hosokawa R, Kimura T, Tamaki N, Komeda M, et al. Cardiac functional analysis with multi-detector row CT and segmental reconstruction algorithm: comparison with echocardiography, SPECT, and MR imaging. *Radiology.* 2005;234:381-90.
315. Rizvi A, Deano RC, Bachman DP, Xiong G, Min JK, and Truong QA. Analysis of ventricular function by CT. *J Cardiovasc Comput Tomogr.* 2014;9:1-12.
316. Raman SV, Shah M, McCarthy B, Garcia A, and Ferketich AK. Multi-detector row cardiac computed tomography accurately quantifies right and left ventricular size and function compared with cardiac magnetic resonance. *Am Heart J.* 2006;151:736-44.
317. van der Vleuten PA, de Jonge GJ, Lubbers DD, Tio RA, Willems TP, Oudkerk M, and Zijlstra F. Evaluation of global left ventricular function assessment by dual-source computed tomography compared with MRI. *Eur Radiol.* 2009;19:271-7.
318. Asferg C, Usinger L, Kristensen TS, and Abdulla J. Accuracy of multi-slice computed tomography for measurement of left ventricular ejection fraction compared with cardiac magnetic resonance imaging and two-dimensional transthoracic echocardiography: a systematic review and meta-analysis. *Eur J Radiol.* 2012;81:e757-62.
319. Groen JM, van der Vleuten PA, Greuter MJ, Zijlstra F, and Oudkerk M. Comparison of MRI, 64-slice MDCT and DSCT in assessing functional cardiac parameters of a moving heart phantom. *Eur Radiol.* 2009;19:577-83.
320. Pursnani A, Lee A, Mayrhofer T, Panagia M, Sharma U, Abbara S, Hoffmann U, Ghoshhajra BB. Feasibility of a radiation dose conserving CT protocol for myocardial function assessment. *Br J Radiol.* 2014 Aug;87(1040):20130755

321. Takx RA, Moscariello A, Schoepf UJ, Barraza JM Jr, Nance JW Jr, Bastarrika G, Das M, Meyer M, Wildberger JE, Schoenberg SO, Fink C, Henzler T. Quantification of left and right ventricular function and myocardial mass: comparison of low-radiation dose 2nd generation dual-source CT and cardiac MRI. *Eur J Radiol.* 2012 Apr;81(4):e598-604
322. Janousek J, Gebauer RA, Abdul-Khaliq H, Turner M, Kornyei L, Grollmuss O, Rosenthal E, Villain E, Fruh A, Paul T, et al. Cardiac resynchronisation therapy in paediatric and congenital heart disease: differential effects in various anatomical and functional substrates. *Heart.* 2009;95:1165-71.
323. Tsai IC, Huang JL, Ueng KC, Hung YW, Hung CF, Liao WC, Lei HY, Chen MC, Tsai WL, Chen SA, et al. Global and regional wall motion abnormalities of pacing-induced heart failure assessed by multi-detector row CT: a patient and canine model study. *Int J Cardiovasc Imaging.* 2010;26:223-35.
324. Selamet Tierney ES, Pigula FA, Berul CI, Lock JE, del Nido PJ, and McElhinney DB. Mitral valve replacement in infants and children 5 years of age or younger: evolution in practice and outcome over three decades with a focus on supra-annular prosthesis implantation. *J Thorac Cardiovasc Surg.* 2008;136:954-61, 61 e1-3.
325. Caldarone CA, Raghuvver G, Hills CB, Atkins DL, Burns TL, Behrendt DM, and Moller JH. Long-term survival after mitral valve replacement in children aged <5 years: a multi-institutional study. *Circulation.* 2001;104:1143-7.
326. Alkadhi H, Desbiolles L, Husmann L, Plass A, Leschka S, Scheffel H, Vachenauer R, Schepis T, Gaemperli O, Flohr TG, et al. Aortic regurgitation: assessment with 64-section CT. *Radiology.* 2007;245:111-21.
327. Feuchtner G, Plank F, Uprimny C, Chevtchik O, and Mueller S. Paravalvular prosthetic valve abscess detected with 18FDG-PET/128-slice CT image fusion. *Eur Heart J Cardiovasc Imaging.* 2012;13:276-7.
328. Chan J, Marwan M, Schepis T, Ropers D, Du L, and Achenbach S. Images in cardiovascular medicine. Cardiac CT assessment of prosthetic aortic valve dysfunction secondary to acute thrombosis and response to thrombolysis. *Circulation.* 2009;120:1933-4.
329. Ghersin E, Lessick J, Agmon Y, Engel A, Kophit A, and Adler Z. Candida prosthetic valve endocarditis: the complementary role of multidetector computed tomography and transoesophageal echocardiography in preoperative evaluation. *Australas Radiol.* 2007;51 Suppl:B231-4.
330. Goldstein SA, Taylor AJ, Wang Z, and Weigold WG. Prosthetic mitral valve thrombosis: cardiac CT, 3-dimensional transesophageal echocardiogram, and pathology correlation. *J Cardiovasc Comput Tomogr.* 2010;4:221-3.

331. Habets J, Symersky P, van Herwerden LA, de Mol BA, Spijkerboer AM, Mali WP, and Budde RP. Prosthetic heart valve assessment with multidetector-row CT: imaging characteristics of 91 valves in 83 patients. *Eur Radiol.* 2011;21:1390-6.
332. Li X, Tang L, Zhou L, Duan Y, Yanhui S, Yang R, Wu Y, and Kong X. Aortic valves stenosis and regurgitation: assessment with dual source computed tomography. *Int J Cardiovasc Imaging.* 2009;25:591-600.
333. Symersky P, Habets J, Westers P, de Mol BA, Prokop M, and Budde RP. Prospective ECG triggering reduces prosthetic heart valve-induced artefacts compared with retrospective ECG gating on 256-slice CT. *Eur Radiol.* 2012;22:1271-7.
334. DeLeon SY, LoCicero J, 3rd, Ilbawi MN, and Idriss FS. Repeat median sternotomy in pediatrics: experience in 164 consecutive cases. *The Annals of thoracic surgery.* 1986;41:184-8.
335. Russell JL, LeBlanc JG, Sett SS, and Potts JE. Risks of repeat sternotomy in pediatric cardiac operations. *The Annals of thoracic surgery.* 1998;66:1575-8.
336. Kirshbom PM, Myung RJ, Simsic JM, Kramer ZB, Leong T, Kogon BE, and Kanter KR. One thousand repeat sternotomies for congenital cardiac surgery: risk factors for reentry injury. *Ann Thorac Surg.* 2009;88:158-61.
337. Herman KO, Schoepf UJ, Bradley SM, and Hlavacek AM. Sternal erosion detected by computed tomographic angiography before repeat sternotomy in an adolescent with congenital heart disease. *Journal of cardiovascular computed tomography.* 2010;4:66-9.
338. Adibi A, Mohajer K, Plotnik A, Tognolini A, Biniwale R, Cheng W, and Ruehm SG. Role of CT and MRI prior to redo sternotomy in paediatric patients with congenital heart disease. *Clin Radiol.* 2014;69:574-80.
339. Sorantin E, Riccabona M, Stucklschweiger G, Guss H, and Fötter R. Experience with volumetric (320 rows) pediatric CT. *Eur J Radiol.* 2012;82:1091-7.
340. Greenberg SB. Rebalancing the risks of Computed Tomography and Magnetic Resonance imaging. *Pediatr Radiol.* 2011;41:951-2.
341. Odegard KC, DiNardo JA, Kussman BD, Shukla A, Harrington J, Casta A, McGowan FX, Jr., Hickey PR, Bacha EA, Thiagarajan RR, et al. The frequency of anesthesia-related cardiac arrests in patients with congenital heart disease undergoing cardiac surgery. *Anesth Analg.* 2007;105:335-43.
342. Girshin M, Shapiro V, Rhee A, Ginsberg S, and Inchiosa MA, Jr. Increased risk of general anesthesia for high-risk patients undergoing magnetic resonance imaging. *J Comput Assist Tomogr.* 2009;33:312-5.

343. Dorfman AL, Odegard KC, Powell AJ, Laussen PC, and Geva T. Risk factors for adverse events during cardiovascular magnetic resonance in congenital heart disease. *J Cardiovasc Magn Reson*. 2007;9:793-8.
344. Melloni C. Morbidity and mortality related to anesthesia outside the operating room. *Minerva Anesthesiol*. 2005;71:325-34.
345. Flick RP, Katusic SK, Colligan RC, Wilder RT, Voigt RG, Olson MD, Sprung J, Weaver AL, Schroeder DR, and Warner DO. Cognitive and behavioral outcomes after early exposure to anesthesia and surgery. *Pediatrics*. 2011;128:e1053-61.
346. Hansen TG, and Flick R. Anesthetic effects on the developing brain: insights from epidemiology. *Anesthesiology*. 2009;110:1-3.
347. Rappaport B, Mellon RD, Simone A, and Woodcock J. Defining safe use of anesthesia in children. *N Engl J Med*. 2011;364:1387-90.
348. DiMaggio C, Sun LS, Kakavouli A, Byrne MW, and Li G. A retrospective cohort study of the association of anesthesia and hernia repair surgery with behavioral and developmental disorders in young children. *J Neurosurg Anesthesiol*. 2009;21:286-91.
349. Cauldwell C. Anesthesia risks associated with pediatric imaging. *Pediatr Radiol*. 2011;41:949-50.
350. Creeley CE, and Olney JW. The young: neuroapoptosis induced by anesthetics and what to do about it. *Anesth Analg*. 2010;110:442-8.
351. Ing C, DiMaggio C, Whitehouse A, Hegarty MK, Brady J, von Ungern-Sternberg BS, Davidson A, Wood AJ, Li G, and Sun LS. Long-term differences in language and cognitive function after childhood exposure to anesthesia. *Pediatrics*. 2012;130:e476-85.
352. Kaste SC, and Young CW. Safe use of power injectors with central and peripheral venous access devices for pediatric CT. *Pediatr Radiol*. 1996;26:499-501.
353. Rigsby CK, Gasber E, Seshadri R, Sullivan C, Wyers M, and Ben-Ami T. Safety and efficacy of pressure-limited power injection of iodinated contrast medium through central lines in children. *AJR Am J Roentgenol*. 2007;188:726-32.
354. Amaral JG, Traubici J, BenDavid G, Reintamm G, and Daneman A. Safety of power injector use in children as measured by incidence of extravasation. *AJR Am J Roentgenol*. 2006;187:580-3.
355. Hunt CH, Hartman RP, and Hesley GK. Frequency and severity of adverse effects of iodinated and gadolinium contrast materials: retrospective review of 456,930 doses. *AJR Am J Roentgenol*. 2009;193:1124-7.

356. Mitchell AM, Jones AE, Tumlin JA, and Kline JA. Immediate complications of intravenous contrast for computed tomography imaging in the outpatient setting are rare. *Acad Emerg Med*. 2011;18:1005-9.
357. Haussler MD. Safety and patient comfort with iodixanol: a postmarketing surveillance study in 9515 patients undergoing diagnostic CT examinations. *Acta Radiol*. 2010;51:924-33.
358. Mortelet KJ, Oliva MR, Ondategui S, Ros PR, and Silverman SG. Universal use of nonionic iodinated contrast medium for CT: evaluation of safety in a large urban teaching hospital. *AJR Am J Roentgenol*. 2005;184:31-4.
359. Dillman JR, Strouse PJ, Ellis JH, Cohan RH, and Jan SC. Incidence and severity of acute allergic-like reactions to i.v. nonionic iodinated contrast material in children. *AJR Am J Roentgenol*. 2007;188:1643-7.
360. Callahan MJ, Poznauskis L, Zurakowski D, and Taylor GA. Nonionic iodinated intravenous contrast material-related reactions: incidence in large urban children's hospital--retrospective analysis of data in 12,494 patients. *Radiology*. 2009;250:674-81.
361. Stacul F, van der Molen AJ, Reimer P, Webb JA, Thomsen HS, Morcos SK, Almen T, Aspelin P, Bellin MF, Clement O, et al. Contrast induced nephropathy: updated ESUR Contrast Media Safety Committee guidelines. *Eur Radiol*. 2011;21:2527-41.
362. Kitajima K, Maeda T, Watanabe S, and Sugimura K. Recent issues in contrast-induced nephropathy. *Int J Urol*. 2011;18:686-90.
363. Kalva SP, Sahani DV, Hahn PF, and Saini S. Using the K-edge to improve contrast conspicuity and to lower radiation dose with a 16-MDCT: a phantom and human study. *J Comput Assist Tomogr*. 2006;30:391-7.
364. Achenbach S, Marwan M, Schepis T, Pflederer T, Bruder H, Allmendinger T, Petersilka M, Anders K, Lell M, Kuettner A, et al. High-pitch spiral acquisition: a new scan mode for coronary CT angiography. *J Cardiovasc Comput Tomogr*. 2009;3:117-21.
365. Halliburton SS, Abbara S, Chen MY, Gentry R, Mahesh M, Raff GL, Shaw LJ, and Hausleiter J. SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT. *J Cardiovasc Comput Tomogr*. 2011;5:198-224.
366. de Graaf FR, Schuijf JD, van Velzen JE, Kroft LJ, de Roos A, Sieders A, Jukema JW, Schalij MJ, van der Wall EE, and Bax JJ. Evaluation of contraindications and efficacy of oral Beta blockade before computed tomographic coronary angiography. *Am J Cardiol*. 2010;105:767-72.
367. Mahabadi AA, Achenbach S, Burgstahler C, Dill T, Fischbach R, Knez A, Moshage W, Richartz BM, Ropers D, Schroder S, et al. Safety, efficacy, and indications of beta-adrenergic receptor blockade to reduce heart rate prior to coronary CT angiography. *Radiology*. 2010;257:614-23.

368. Pannu HK, Sullivan C, Lai S, and Fishman EK. Evaluation of the effectiveness of oral Beta-blockade in patients for coronary computed tomographic angiography. *J Comput Assist Tomogr.* 2008;32:247-51.
369. Rigsby CK, deFreitas RA, Nicholas AC, Leidecker C, Johaneck AJ, Anley P, Wang D, and Uejima T. Safety and efficacy of a drug regimen to control heart rate during 64-slice ECG-gated coronary CTA in children. *Pediatr Radiol.* 2010;40:1880-9.
370. Achenbach S, Manolopoulos M, Schuhback A, Ropers D, Rixe J, Schneider C, Krombach GA, Uder M, Hamm C, Daniel WG, et al. Influence of heart rate and phase of the cardiac cycle on the occurrence of motion artifact in dual-source CT angiography of the coronary arteries. *J Cardiovasc Comput Tomogr.* 2012;6:91-8.
371. Weustink AC, Neefjes LA, Kyrzopoulos S, van Straten M, Neoh Eu R, Meijboom WB, van Mieghem CA, Capuano E, Dijkshoorn ML, Cademartiri F, et al. Impact of heart rate frequency and variability on radiation exposure, image quality, and diagnostic performance in dual-source spiral CT coronary angiography. *Radiology.* 2009;253:672-80.
372. Araoz PA, Kirsch J, Primak AN, Braun NN, Saba O, Williamson EE, Harmsen WS, Mandrekar JN, and McCollough CH. Optimal image reconstruction phase at low and high heart rates in dual-source CT coronary angiography. *Int J Cardiovasc Imaging.* 2009;25:837-45.
373. Einstein AJ, Henzlova MJ, and Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. *JAMA.* 2007;298:317-23.
374. Hoffmann A, Engelfriet P, and Mulder B. Radiation exposure during follow-up of adults with congenital heart disease. *Int J Cardiol.* 2007;118:151-3.
375. Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, and Henzlova MJ. Radiation dose to patients from cardiac diagnostic imaging. *Circulation.* 2007;116:1290-305.
376. Brenner D, Elliston C, Hall E, and Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. *AJR Am J Roentgenol.* 2001;176:289-96.
377. Raff GL. Radiation dose from coronary CT angiography: five years of progress. *J Cardiovasc Comput Tomogr.* 2010;4:365-74.
378. Ghoshhajra BB, Lee AM, Engel LC, Celeng C, Kalra MK, Brady TJ, Hoffmann U, Westra SJ, and Abbara S. Radiation dose reduction in pediatric cardiac computed tomography: experience from a tertiary medical center. *Pediatr Cardiol.* 2014;35:171-9.
379. Dougeni E, Faulkner K, and Panayiotakis G. A review of patient dose and optimisation methods in adult and paediatric CT scanning. *Eur J Radiol.* 2012;81:e665-83.

380. Siegel MJ, Hildebolt C, and Bradley D. Effects of automated kilovoltage selection technology on contrast-enhanced pediatric CT and CT angiography. *Radiology*. 2013;268:538-47.
381. Siegel MJ, Ramirez-Giraldo JC, Hildebolt C, Bradley D, and Schmidt B. Automated low-kilovoltage selection in pediatric computed tomography angiography: phantom study evaluating effects on radiation dose and image quality. *Invest Radiol*. 2013;48:584-9.
382. Frush DP. Pediatric CT: practical approach to diminish the radiation dose. *Pediatr Radiol*. 2002;32:714-7; discussion 51-4.
383. Frush DP. Pediatric dose reduction in computed tomography. *Health Phys*. 2008;95:518-27.
384. Goo HW, and Suh DS. Tube current reduction in pediatric non-ECG-gated heart CT by combined tube current modulation. *Pediatr Radiol*. 2006;36:344-51.
385. Linton OW, and Mettler FA, Jr. National conference on dose reduction in CT, with an emphasis on pediatric patients. *AJR Am J Roentgenol*. 2003;181:321-9.
386. Stolzmann P, Goetti R, Baumueller S, Plass A, Falk V, Scheffel H, Feuchtner G, Marincek B, Alkadhi H, and Leschka S. Prospective and retrospective ECG-gating for CT coronary angiography perform similarly accurate at low heart rates. *Eur J Radiol*. 2011;79:85-91.
387. Zhang T, Wang W, Luo Z, Wang D, Bai J, Han D, and Shen B. Initial experience on the application of 320-row CT angiography with low-dose prospective ECG-triggered in children with congenital heart disease. *Int J Cardiovasc Imaging*. 2011;28:1787-97.
388. AAPM Task Group 23 of the Diagnostic Imaging Council CT Committee. The Measurement, Reporting, and Management of Radiation Dose in CT [AAPM Report 96].2008. ISBN 9781888340730.
389. AAPM Task Group 204 of Computer Tomography Subcommittee. Size-specific dose estimates (SSDE) in pediatric and adult body CT examinations. 2011. ISBN 9781936366088.
390. Hollingsworth CL, Yoshizumi TT, Frush DP, Chan FP, Toncheva G, Nguyen G, Lowry CR, and Hurwitz LM. Pediatric cardiac-gated CT angiography: assessment of radiation dose. *AJR Am J Roentgenol*. 2007;189:12-8.
391. Gherardi GG, Iball GR, Darby MJ, and Thomson JD. Cardiac computed tomography and conventional angiography in the diagnosis of congenital cardiac disease in children: recent trends and radiation doses. *Cardiol Young*. 2011;21:616-22.
392. Watson TG, Mah E, Joseph Schoepf U, King L, Huda W, and Hlavacek AM. Effective Radiation Dose in Computed Tomographic Angiography of the Chest and Diagnostic Cardiac Catheterization in Pediatric Patients. *Pediatr Cardiol*. 2012;34:518-24.

393. Johnson JN, Hornik CP, Li JS, Benjamin DK, Jr., Yoshizumi TT, Reiman RE, Frush DP, and Hill KD. Cumulative radiation exposure and cancer risk estimation in children with heart disease. *Circulation*. 2014;130:161-7.
394. Gerber TC, Carr JJ, Arai AE, Dixon RL, Ferrari VA, Gomes AS, Heller GV, McCollough CH, McNitt-Gray MF, Mettler FA, et al. Ionizing radiation in cardiac imaging: a science advisory from the American Heart Association Committee on Cardiac Imaging of the Council on Clinical Cardiology and Committee on Cardiovascular Imaging and Intervention of the Council on Cardiovascular Radiology and Intervention. *Circulation*. 2009;119:1056-65.