



INDIAN COLLEGE OF RADIOLOGY AND IMAGING

ICRI SUB-SPECIALTY GROUP FOR CARDIAC IMAGING

STANDARD REPORTING FORMATS & BASIC IMAGING PROTOCOLS FOR CARDIAC CT

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PART A: STANDARD REPORTING FORMATS

PART B: BASIC IMAGING PROTOCOLS

PART A: Standard Reporting Formats

I. CT CORONARY ANGIO REPORTING TEMPLATE

NAME: Age/Sex Dt:

REF.BY: ID No-

Clinical information:

Comparison:

Limitations of study: If any

MSCT CORONARY ANGIOGRAPHY:

Technique:

Plain CT calcium score scan was performed using prospective ECG gating.

Contrast enhanced prospective / retrospective ECG gated MSCT coronary angiogram was performed with a total of [mention amount] I.V. injection of non-ionic contrast [mention type] through anticubital vein at a rate of 5 mL/sec without adverse reaction. Serum creatinine was ___ mg/dL . If IV contrast material had not been administered, the likelihood of detecting abnormalities relevant to the patient's condition would have been substantially decreased.

Heart rate ___ bpm and rhythm - normal at time of scan

Medication 1. oral/IV beta blockers given during study. 2. Nitroglycerine dose

Specify system name with collimator and gantry rotation time

Complex image reconstruction post processing was likewise performed as indicated to increase the sensitivity of detecting clinically relevant pathology.

Findings:

1. CORONARY ARTERIES:

Origin: Normal/mention if anomaly present in detail

Dominance: Right/Left/Co-dominant

Calcium score – Nil

Left Main coronary Artery:

- size, Appears normal in course and calibre. There is no evidence of stenosis or plaque identified. LMCA bifurcates/trifurcates into LAD , LCX and RI.

LAD: - Type A/B/C vessel.

Appears normal in course and calibre. There is no evidence of stenosis or plaque identified.

Septal branches: Appear normal in course and calibre. There is no evidence of stenosis or plaque identified.

Diagonal arteries – Mention number of major diagonals appreciated on CT study e.g D1,D2, D3 etc. Appear normal in course and caliber, whether good sized $\geq 2\text{mm}$. There is no evidence of stenosis or plaque identified.

LCX: -

Appears normal in course and calibre. There is no evidence of stenosis or plaque identified.

Obtuse Marginal branches: - Mention number of major OM's appreciated on CT study e.g OM 1, OM 2, OM 3 etc. Appear normal in course and caliber, whether good sized $\geq 2\text{mm}$. There is no evidence of stenosis or plaque identified.

RCA-

Appears normal in course and calibre. There is no evidence of stenosis or plaque identified.

Sino-atrial nodal branch: Arises from RCA/LCx.

PDA and PLV - It is well seen on this study through RCA/LCx.

2. SYSTEMIC VASCULATURE:

LIMA and RIMA (Left and Right internal mammary arteries) appear normal.

Mention if relevant ascending aortic or aortic valve abnormality noted.

3. PULMONARY VASCULATURE:

Mention if relevant abnormality noted.

4. NON-VASCULAR:

Visualized lung fields appear normal.

5. CARDIAC FUNCTION ASSESSMENT

Estimated EF (visual): 60%

Chambers size: normal. No evidence of thrombosis or mass lesion is seen.

Wall motion: normal.

IMPRESSION –

1. POSITIVE FOR STENOSIS

Any major coronary artery or branch :

An ____ mm long significant / non-significant stenosis (mention range of stenosis %) in proximal / mid/ distal vessel (mention relation to near by major side branch or distance from origin whichever is applicable) due to concentric / eccentric as well as calcified/ non-calcified/mixed plaques.

Mention if any of high risk plaque characteristics like spotty calcification, low HU, napkin ring sign or positive remodelling are present or not.

Also important to mention distal opacification.

CAD-RADS (optional) For details refer to link <http://dx.doi.org/10.1016/j.jcct.2016.04.005>

For example:

LAD

- ✓ Type B LAD.
- ✓ FOCAL (5 mm length) MODERATE STENOSIS (~50-69%) IN MID LAD ACROSS D2 BRANCH DUE TO CONCENTRIC NON-CALCIFIED PLAQUE. No e/o spotty calcification or positive remodelling seen.
- ✓ *Rest of distal LAD appears patent with atheromatous changes.*

2. POSITIVE FOR COMPLETE OCCLUSION

Any major coronary artery: Complete chronic occlusion of ____ mm length segment, across / not involving branch vessel. Distal vessel shows / does not show contrast opacification, mention scoring according to J-CTO or CT RECTOR score.

3. POSTIVE FOR STENT

Stent – mention segment of coronary artery where stent is placed, patency with or without neo-intimal hyperplasia / with or without significant in-stent-restenosis (ISR). Mention stent complications like fracture or pseudoaneurysm or infection if any.

II. CONGENITAL HEART DISEASE CT REPORTING FORMAT

NAME: Age/Sex DT:

REF.BY: ID No-

Clinical information:

Comparison:

CARDIAC CT ANGIOGRAPHY

Technique:

Multislice Cardiac CT angiography was performed after [mention amount] I.V. injection of non-ionic contrast [mention type] through antecubital /leg vein without any adverse reaction. If IV contrast material had not been administered, the likelihood of detecting abnormalities relevant to the patient's condition would have been substantially decreased. Complex image reconstruction post processing was likewise performed as indicated to increase the sensitivity of detecting clinically relevant pathology.

Specify if ECG gating used

FINDINGS:

1. SITUS

Cardiac Situs – Levocardia/dextrocardia/mesocardia , atrial isomerism

Visceral Situs – solitus/inversus/ambiguous

Liver – On right side, normal.

Spleen – On left side, normal.

Stomach – On left side.

Bronchial situs - solitus/inversus/ambiguous

2. ATRIA

Right atrium – Normal/Dilated/any other relevant abnormality

Left atrium – Normal/Dilated/any other relevant abnormality

Atrial appendages- Mention if L or D juxta posed both atrial appendage +/-

Inter-atrial septum – Intact/ASD [Mention type & size]

3. Atrioventricular connection

Univentricular/ biventricular

Concordant/ discordant/ mixed

Status of AV valve: patent/atretic/common AV valve

4. VENTRICLES

Ventricular looping- D or L - loop

Right ventricle – Normal/Dilated/hypoplastic/any other relevant abnormality

Left ventricle – Normal/Dilated/hypoplastic/any other relevant abnormality

Inter- ventricular septum – Intact/VSD [Mention type & size]

5. Ventriculoarterial connection

Concordant/discordant/double outlet /single outlet

Outflow obstruction if any

6. GREAT ARTERIAL RELATIONSHIP

NRGA (Normally related great arteries) / L-posed /D-posed aorta

7. AORTA

Origin – From left ventricle/right ventricle

Arch- Left/right or double arch with branching pattern

Coarctation: Absent. [If present, mention type & relevant dimensions]

Descending thoracic aorta at diaphragm level – ____ mm.

Dilated ascending aorta if present – ____ mm.

Proximal coronary anatomy: or if any anomaly should be mentioned here.

8. PULMONARY ARTERIES

Origin – From right ventricle/left ventricle

RVOT- Normal/pulmonary stenosis/atresia

Confluence: Present/absent

Main pulmonary trunk: Mention size

RPA: Mention size in orthogonal double oblique plane if possible at proximal and at hilar level

LPA: Mention size in orthogonal double oblique plane if possible at proximal and at hilar level

Mention if any branch pulmonary stenosis present.

PULMONARY VALVE: Thickened / Normal/Absent

9. COLLATERALS –

Describe in detail if major aorto-pulmonary collaterals [MAPCAs] present.

e.g. 1) A large collateral from descending thoracic aorta at T7 level from 12-2 o'clock position, measures 11.4 mm at origin and immediately divides into two branches.

Right branch– Measures 7 mm, runs anterior to right lower lobe bronchus with stenosis (mention size) and supply right lower lobe.

Left branch – Measures 4.5mm, tortuous course posterior to left lower lobe bronchus and connects to LPA at hilar level.

10. PDA – Absent/If present mention type/tortuosity/stenosis +/- at pulmonary end

11. PULMONARY VEINS – All pulmonary veins drain normally into left atrium. No evidence of abnormal pulmonary venous drainage.

If abnormal drainage seen –PAPVC/TAPVC- describe in detail.

Wherever relevant – Mention each pulmonary veins dimension 1 cm before its junction with left atrium

12. SYSTEMIC VEINS

SVC – single, drains into right atrium. If bilateral – Mention if communicating vein present or absent, also provide drainage of persistent left SVC

IVC – No interruption, supra-hepatic IVC drains into right atrium. If interruption present, provide detailed drainage.

Anomalous hepatic vein draining into atrium directly.

Veno-venous collaterals

13. OTHER FINDINGS

Pericardial effusion – Absent/present

Both Lungs – sidedness, lung arborisation , AVM

Liver - hepatic & portal vein anomalies

Thoracic rib cage : pectus / kyphoscoliosis

14. POST OPERATIVE CHANGES

Patency of graft/baffle/ conduit/stent

Thrombus/ calcification / leak

Relationship of cardiac chambers to sternum/sternal wires

IMPRESSION –

For normal study

Situs solitus, levocardia, left aortic arch, normal systemic & pulmonary venous connection, concordant atrioventricular & ventriculo arterial connection, intact atrial & ventricular septum, no PDA, NREGA, good sized confluent branch pulmonary arteries, no coarctation, no collaterals, normal coronary origin, normal sized chambers

PART B: Basic Imaging Protocols

III. CT Coronary angiogram protocol

Technical Parameters

Basic CT Scanner Requirement

For high spatial and native temporal resolution, three parameters are important:

- Small detector element width
- Multiple rows of detectors to improve coverage of anatomy
- Fast gantry rotation

A scanner with 128 rows of detector covers 8 cm in every rotation and will be better than a scanner with 64 rows of detector that will only cover 4 cm with every rotation.

Lesser the number of rotations required to cover the heart, better the image quality with reduced step/registration artifacts.

The minimum required specifications of a cardiac CT scanner, as per the American College of Radiology (ACR) recommendation are shown in the table.

• A 64-row detector scanner or more
• Minimum in-plane resolution of $\leq 0.5 \times 0.5$ mm axial and z-axis spatial resolution of < 1 mm.
• Temporal resolution of ≤ 250 ms.

Tube potential (kVp) and current (mA)

Cardiac CT scanners are capable of generating varied tube potential between 70-150 kVp. Lower tube potentials can be employed in pediatric age group or in patients with low BMI (body mass index) to reduce radiation dose. Higher kVp is required in patients with moderate to high BMI to ensure good quality of angiography. Automatic selection of tube potential is also possible in some scanners.

Tube current (represented as mA) will depend on the patient body habitus, reconstruction algorithm being employed and the scanner capabilities. Tube current modulation methods, such as 'Automatic Exposure Control (AEC)' can be employed to alter the current based on the density of the body part being scanned⁹. ECG based tube current modulation is also possible whereby higher current is passed during a specific phase of the cardiac cycle.

Learning point:

*Keep the tube potential (kVp) and tube current (mA) as low as possible.

*Use scanner provided tube current modulation methods to maintain image quality and reduce radiation exposure.

ECG gating

ECG gating coordinates imaging with a particular phase in the cardiac cycle. Three different protocols are possible:

1. Prospective ECG gating

2. Retrospective ECG gating
3. ECG guided dose modulation

Prospective gating reduces radiation dose significantly and should be used in patients with stable and controlled heart rate.

Acquisition with retrospective gating is required for Ventricular functional analysis and valve motion evaluation.

Image reconstruction and post-processing

Iterative reconstruction algorithms allow a reduction in radiation exposure without compromising image quality.

Contrast Parameters

- Dual head injectors are preferred for contrast injection
- High injection rates of 4 to 5ml/sec or more are used for cardiac CT.
- Using contrast with low iodine concentration helps in reducing kVp and thereby the total radiation exposure.
- Bolus tracking technique is preferred for the timing of the scan

Radiation Exposure

- All attempts should be made to reduce patient radiation exposure.
- Dose Length Product (DLP) of all cardiac CT studies should be monitored with regular auditing of results.

Factors that help in reduction of radiation exposure

1. Minimize patient heart rate
2. Reduce Tube Voltage
3. Reduce Tube current or use available dose modulation method (AEC)
4. Increase pitch
5. Use fastest rotation speed of gantry
6. Prospective gating or ECG based tube current modulation
7. Optimize cranio-caudal coverage (lesser the better)
8. Use iterative reconstruction (modify as per user choice for image quality)
9. Avoid ECG gating in pediatric cases (if coronary data is not required)
- 10.** Use contrast with lower iodine concentration or reduce volume of high iodine concentration contrast
- 11.** Keep the patient in the center of gantry- critical for small babies
- 12.** Avoid multiple runs, plain scan and calcium score if not indicated

Types of Cardiac Studies

Cardiac CT studies can be broadly classified into these three categories.

- CT Calcium Score
- CT Coronary Angiography: CTCA, Double/Triple Rule Out, CT Myocardial Perfusion
- CT Cardiac for Congenital Heart Disease

CT Coronary Calcium Study

Indication

- Asymptomatic patients with an intermediate risk of Coronary Artery Disease (CAD)
 - Diabetics above the age of 40 years
 - Patients with low to intermediate risk of CAD
 - Patients with low risk but a family history of premature CAD
- Follow up studies after 5 years gap may be justified in patients, except those who have a score of >400 or in those who have had two scans with 0 score, 5 years apart.

Patient Preparation

This is a non-contrast study and no specific patient preparation is required. ECG leads are placed in the upper (at the level of the shoulder) and lower aspect (below rib cage) of the torso. Good ECG tracing should be ensured with an upward-directed R wave. Procedure should be explained and appropriate breathing instructions (shallow inspiration) given.

Scanning Parameters

The patient should be supine on the table with arms placed above the shoulder in a comfortable position. Prospective ECG gating is preferred. Scanogram are performed covering the entire chest in both frontal and lateral views. Small field of view (FOV), covering the heart, is selected with a 512x512 or higher image matrix for reconstruction. The craniocaudal coverage should be between the tracheal bifurcation and the lower border of the heart. Tube potential should be 120 kV and the tube current could be modulated. Images are acquired and reconstructed at a thickness of 3 mm.

Image Assessment

Quantitative assessment of CAC, using validated software, is recommended for accurate quantification of CAC and risk stratification. The method proposed by Agatston et al, is the universally used method for estimation of CAC score in clinical practice. Standardized reporting template, CAC DRS (coronary artery calcium data and reporting system), is recommended.

Learning point:

**** CT CAC scoring is extremely useful in risk stratification of asymptomatic patients with low to intermediate risk of CAD.***

**** Prospective gating is used in this non-contrast study and quantitative assessment of Agatston score should be provided***

CT Coronary Angiography

Indications:

Coronary Arteries

- Unexplained or atypical chest pain in patients with low or intermediate risk profile
- Typical or atypical chest pain with normal or equivocal stress test and ECG
- Unexplained acute chest pain with negative cardiac enzymes and normal or equivocal ECG findings
- Unexplained acute chest pain with (negative cardiac enzymes and normal or equivocal ECG findings) differential diagnosis of CAD, acute aortic syndrome and pulmonary embolism
- Intermediate pretest probability in asymptomatic individuals
- Family history of premature CAD
- Evaluation of coronary artery bypass grafts
- To look for patency of stent in left main coronary artery in asymptomatic patients.
- Assessment of coronary artery stents $\geq 3\text{mm}$ in diameter in asymptomatic patients
- Evaluation of ischemic etiology for a newly diagnosed cardiomyopathy and/or heart failure
- Intermediate pretest probability in coronary evaluation before non-cardiac surgery
- Suspected anomalous coronary artery anatomy
- Evaluation of re-implanted coronary artery
- Diagnosis or follow up of Kawasaki disease

Cardiac Structure (post echocardiography)

- Cardiac and pericardial mass
- Chronic pericarditis
- Complex congenital structural disorders
- Right or Left sided chamber obstructive disorders
- Systemic and pulmonary venous anomalies
- Aortic and pulmonary artery anomalies

Cardiac Function (post echocardiography)

- Ventricular volume
- Valve (both native/mechanical)

Patient preparation

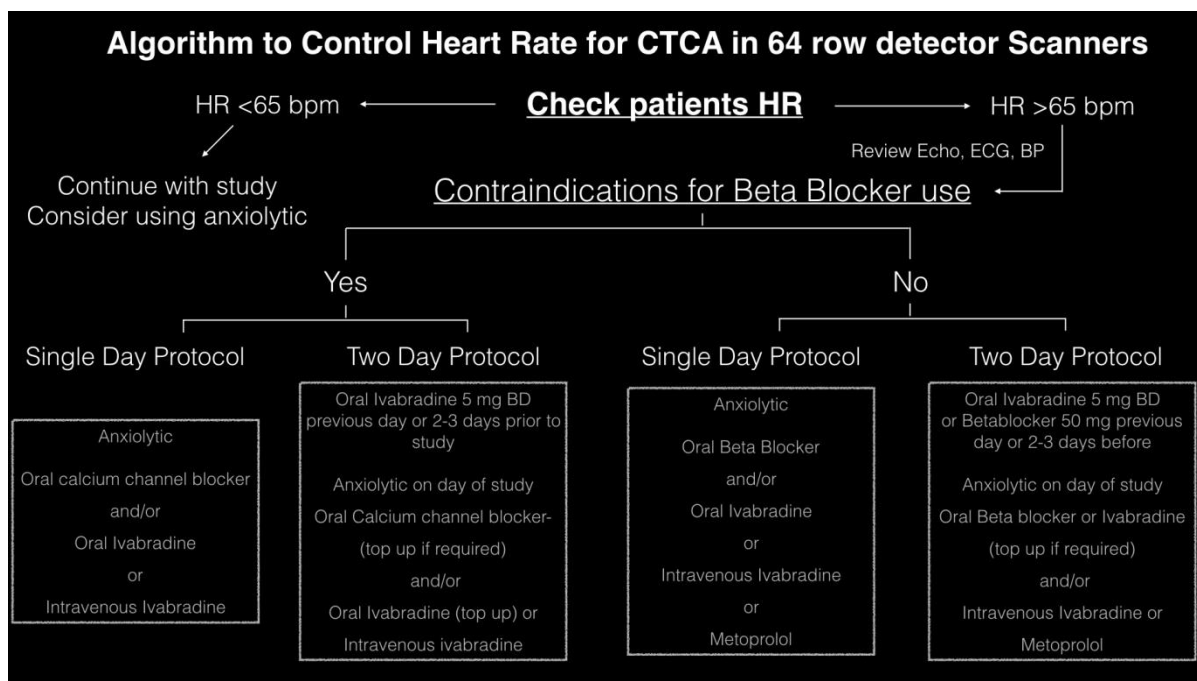
Pre-procedure Instructions: Individual department/internationally recommended guidelines with regards to fasting, contrast allergy and renal profile should be followed. Patients should be advised to avoid caffeine products (tea/coffee/energy drink/carbonated drinks) up to 24 hours before the procedure to help in heart rate control.

Heart Rate Optimization: Ideally, the rhythm should be regular and HR should be between 60-65 bpm. In patients with higher HR, pharmacotherapy can be utilized to reduce the HR.

Short-acting *anxiolytics* to calm the patient and make them more comfortable. Small dose (0.25 mg) of Tab Alprazolam about 30-60 minutes prior to the procedure would suffice. Different options are available to reduce the HR and are depicted in the table.

NAME	Dose (Max)	Advantages	Disadvantages
Oral Metoprolol	50-100 mg (200 mg)	Cost-effective Moderate fast acting Reasonable rate control	Hypotension Contraindicated in heart failure, Asthma/COPD and high degree heart block
IV Metoprolol	2-5 mg (20-25mg)	Fast Acting Easy Access	As Above
Tab Ivabradine	5-15 mg (15 mg)	No effect on BP Can use in asthma/COPD Can use in heart blocks	Delayed response than beta-blocker
IV Ivabradine	5-15 mg (15mg)	Fast action No effect on BP Can use in asthma/COPD Can use in heart blocks	
Oral Diltiazem (CCB)	60 mg (180-240mg)	Can use in asthma/COPD	Contraindicated in heart failure Delayed response than beta-blocker

The Chart below depicts an algorithm that can be used to select between different regimes for reduction of HR.



Vasodilation of coronaries using Nitroglycerine (sublingual or as puff) helps improve coronary analysis. It should be administered up to 5 minutes before the scan (1 tab of 0.3mg or up to two puffs). Nitroglycerine is contraindicated in patients with severe aortic stenosis, systolic blood pressure < 100 mmHg and in patients with LV ejection fraction (LVEF) <35%.

Breath-hold practice: Clear instructions should be given to the patient about what to expect during the procedure and how to hold their breath at the appropriate time.

Venous Access: An 18 Gauge venous cannula in the right antecubital vein is preferred. The cannulation of hand veins is avoided because of high flow rate of contrast and high risk of peripheral phlebitis in hand vessels. Left internal mammary artery (LIMA) is the common graft utilized in coronary artery bypass graft (CABG) surgery. Right side injection avoids “streak” artifacts in left subclavian vein and internal mammary artery, allowing assessment of LIMA.

Scanning Parameters

CT CAC:

Excessive CAC can obscure coronary artery lumen and lead to over estimation of stenosis due to blooming artifact of calcium. Therefore, in many centers, CTCA is not performed in patients with an Agatston score of more than 1000. The distribution of calcium along the vessel wall (peripheral better than central) and the coronaries (for example: chunk of calcium in LM bifurcation will impair assessment) help in deciding whether to proceed further with CTCA or refer the patient for CCA. CT CAC data should be reviewed to ensure good breath-hold, any variation in HR and z-axis coverage.

CTCA:

FOV and the craniocaudal coverage are adjusted after checking CT CAC images. Tube potential is modified between 80 and 120 kV, as per the patient, scanner and/or contrast parameters. Tube current modulation is employed. An image matrix of 512 x 512 or greater is preferred and the data is acquired at sub-mm (0.5-0.625mm) thickness. Reconstruction interval (slice gap) is kept to a minimum to get better resolution along the z-axis.

Contrast:

Contrast injection (5ml/sec) is followed by same rate of saline chase and bolus-tracking method is used with ROI placed in the ascending or descending aorta (depending on the individual scanner). The trigger point varies from 150-300 HU depending on the contrast used, time lag between the trigger and the start of scan.

Processing of raw data

At the end of data acquisition, reconstruction of all available phases (with a gap of 5-10% R-R interval) in 3 mm thickness with a gap of 3 mm. These thick section images should be reviewed and the appropriate phase identified with least cardiac motion. At least one systolic (35-50%) and one diastolic (60-80%) reconstruction should be done.

Thin section images are reconstructed with a thickness of 0.625 mm or less with no intervening gaps. The FOV is kept small to cover the heart region only to improve spatial resolution. The best reconstruction algorithm kernel should be chosen to assess the vessels as per the vendor recommendation.

ECG editing may be required in patients with irregular HR or ectopic beats during scan acquisition. These can be done at the scanner console if retrospective gating was utilized. Single-cycle reconstruction (SCR) is an excellent post-processing technique that can improve the quality of CTCA in cases of higher or fluctuating HR.

Post-processing

Images of CTCA are reconstructed in curved MPR for better visualization and assessment. Maximum intensity projection (MIP) and volume rendering techniques are also helpful in understanding the overall course of coronary arteries and their pathologies.

Protocol Modifications

Assessment of Stents: In post-processing, special edge enhancing kernel is used to lower stent wall thickness, improve vessel lumen assessment and estimation of luminal stenosis.

Post CABG assessment: The craniocaudal extent of the study is increased to cover from the thoracic inlet to the lower edge of the heart. Prior information of specific grafts used is essential for planning of the study. In patients with LIMA graft, contrast is injected through the right arm. Caudocranial acquisition may be employed in case the breath-hold period is long, to ensure that the distal grafts are well seen without breathing motion artifacts.

Double Rule Out (Aorta and Coronary Assessment): Contrast injection rate could be modulated (triphasic protocol) with 60% of contrast injected at 5ml/sec or higher and remaining 40% contrast injected at a lower rate of 3 ml/sec followed by saline chase. This will ensure continued opacification of the aorta during the long scan duration.

Triple Rule Out (Aorta, Pulmonary and Coronary Assessment): Triphasic contrast injection protocol; wherein 60% of contrast is injected at 4-5ml/sec and remainder of the contrast is injected in a 50-50% dilution with saline at a rate of 3 ml/sec. The first run will cover the entire thoracic cavity (ECG gated) and the second run covers the entire aorta from lower neck to bifurcation. Tube current and exposure parameters are similar to CTCA.

CT FFR (Fractional Flow Reserve): CT FFR assessment is a software-based technique and employs different levels of machine learning.

CT Myocardial Perfusion: Images are acquired during rest and at peak myocardial stress. Protocols of pharmacological stress, choice of medication, its contraindications and complications are beyond the scope of this paper. Three different methods can be employed based on the scanner available⁴⁵:

- *Static CTP with mono-energetic X ray beam:* This involves standard CTCA data acquired at rest and then during stress. Thick MPR are made and images are analyzed for stress induced perfusion defect (ischemia), fixed perfusion defect (infarction) and normal perfusion.
- *Static CTP with multi-energy X ray beam:* In this technique, spectral characteristics of different tissues when exposed to different energy beams is utilized and is superior to mono-energetic method. Scanners can achieve this by different methods. In dual source CT (DSCT), each tube emits different energy levels while

in some of the single source CT there is rapid switching of kV. Modified detector technology with two layers ('sandwich') of detector can also help in achieving the same results.

- *Dynamic CTP imaging:* This is the best method for assessment of myocardial perfusion and involves repeated acquisition of data during the first-pass of contrast through the myocardium. Images are preferentially performed during systolic phase (as coverage of heart is less). There is high radiation exposure and the breath hold time is also long. Scanners with 16 cm z-axis coverage or second/third generation DSCT (shuttle mode) are required to perform this method.

Image Assessment

Thorough CTCA image assessment includes assessment of MIPs, curved MPRs and 3 dimensional (3D) volume-rendered images. Coronary anatomy, presence/absence of CAD with degree of stenosis needs to be reported. Any stenosis present must be seen in at least two phases to rule-out artifacts. Standardized reporting terminology is recommended for improved communication between different specialists. We recommend the use of Coronary Artery Disease- Reporting and Data System (CAD-RADS) while reporting CTCA studies. In patients with CABG, both the native coronaries and the graft vessels are analyzed and commented upon. A standard reporting approach is advocated to ensure uniformity of reports and clear communication amongst users. Extra coronary abnormalities should be sought and reported. Any urgent or unexpected findings should be communicated to the referral team.

Learning point:

- * *Heart rate control reduces radiation exposure and improves image quality*
- * *High CT CAC score (>1000) may reduce the accuracy of coronary stenosis assessment on CTCA*
- * *Sharp kernel reconstruction should be used to assess coronary stents and areas of high calcium deposition*
- * *Contrast and scan parameters should be changed to acquire double and triple rule out studies*

IV. Cardiac CT protocols for Congenital Heart Disease

Indications for CT in CHD

- Systemic and pulmonary venous/arterial anomalies
- CHD with unclear coronary anatomy
- Evaluation of major aorto-pulmonary collateral arteries (MAPCA)
- Complex CHD (like pulmonary atresia, transposition of great arteries, double outlet right ventricle, atria-ventricular septal defect, heterotaxy syndromes etc.)
- Postoperative assessment of shunts (modified BT shunt, Glenn shunt, Fontan shunt etc.)
- Pulmonary arterial hypertension with unclear etiology
- Evaluation of suspected vascular ring or sling

Patient preparation

Younger children require varying degrees of conscious sedation. General anesthesia is usually not required for cardiac CT. If qualified anesthetist support is not available, oral sedation using pediclorol (Trichlorofos) syrup can be given with a maximum dose of 1ml/kg body weight. Patients' saturation needs to be monitored continuously as some of these children may have baseline cyanosis.

In children with CHD, the HR is high and its control is difficult. On occasions where coronary assessment is critical (for ex: coronary aneurysms/ vasculitis) oral beta-blocker can be used in consultation with a pediatric cardiologist but stat doses are avoided and pre medication over 2-3 days is preferred.

Cannula selection is dependent on the age of the patient and the size of peripheral venous access. Usually $\geq 22G$ cannula can be used in children older than 5 years while $< 22G$ can be used in children younger than 5 years depending on the size of peripheral vein. In adults, 18G venous catheter should be placed. Lower limb venous access is preferred in small children to prevent streak artifacts from contrast in superior vena cava (SVC).

Meticulous procedures should be followed to avoid air injection, as children may have a right to left shunt making them vulnerable to systemic air embolism with significant consequences. Small babies should be covered well to avoid the risk of hypothermia.

Scanning Parameters

Patient should be placed in the iso-center of the gantry using laser beams on the scanner. For smaller babies, an additional patient pad or a vacuum device may be necessary to lift the child further up to the iso-center. The vacuum pad also helps in immobilizing the child and if not available can be replaced by blankets.

Scout images are taken in frontal plane. Non-contrast enhanced scan is avoided to reduce radiation exposure (exception is a case with cardiac mass). The FOV includes the entire thoracic cavity and the upper part of the abdomen (including kidneys). This ensures appropriate assessment of the inferior vena cava (IVC) and the portal venous system and its drainage. The rotation speed should be kept at fastest and the pitch should be higher to enable faster imaging.

Three different protocols can be employed based on the clinical scenario and the scanner at hand. ECG gating may not be possible in older/slower scanners due to high HR.

1. Single Run without ECG gating: This exposes the child to least radiation and is often sufficient in assessment of isolated pathologies, such as coarctation of the aorta. Lowest scan duration is preferred to ensure least breathing motion artifacts.
2. Single Run with ECG gating: This should be employed in patients where coronary assessment is important (Tetralogy of Fallot/Transposition of Great Arteries/Coronary Anomalies etc.). Patients with aortic root pathology, such as aorto-pulmonary window or ruptured sinus of Valsalva, can also be assessed by this study. Radiation exposure will be higher and assessment of pulmonary arterial or systemic venous structures can be difficult in this one phase scan.
3. Double Run (ECG gated and Non-ECG gated): This arguably provides the most comprehensive assessment and can be used in all the complex CHD cases. The first run is ECG gated and only covers from the arch of aorta to diaphragm. The second non-gated run then covers the entire thoracic cavity and the upper abdomen.

This provides both arterial and venous phase imaging and is ideal for assessment of shunts, anomalous venous connections and coronary/aortic pathologies.

Contrast: Bolus-tracking technique is preferred with the ROI set in the right ventricle. In patients with complex anatomy and hemodynamics (for example anomalous systemic venous return), a test bolus technique may perform better. Rate of contrast injection varies according to the size of the IV catheter. Flow rate of 1ml/sec can be used for 24G cannula while 1.5-2.5 ml/sec for 22G cannula, 2-4 ml/sec for 20G catheter and 3-5 ml/sec for 18-16G cannula are recommended. The volume of contrast is restricted to 1 to 2 ml/kg of patient weight followed by saline chase. In adults, rate of contrast injection should be more than 4 ml/sec and should be followed by saline chase.

Good opacification of all the four chambers can be obtained by split-bolus technique. In this, an initial bolus of contrast is followed by a 70%-30% saline to contrast mixture and a final saline chase.

Radiation Risk

Low tube potential should be used. Usage of 70 kV for children weighing <12 kg; 80 kV for 12 to 35 kg; 100 kV for >35 kg is recommended.

The distance between the skin and the focal spot of the CT scanner determines the entrance dose to the skin of the patient (inverse-square law). Therefore positioning the child in the iso-center reduces the radiation dose.

Post Processing

Images should be reconstructed in various planes according to the clinical question. Maximum intensity projection (MIP) is used to visualize vessels better. 3D reconstructions are useful in assessing complex CHD and vessel anomalies and help in demonstrating the main pathology to the clinicians. Images can also be used for rendering 3D models to understand the anatomy better.

Image Analysis

A systematic approach to every study with CHD is essential. Standard reporting templates are useful to reduce errors and also improve communication/understanding between team members. Various 3D rendered images; MPR's are useful in assessing the anatomy in patients with complex CHD.

Learning point:

- * Echocardiography data is important to plan and choose the right protocol for CHD CT*
- * Tube potential should be altered as per patient's body weight*
- * ECG gating should be restricted to specific cases where information regarding coronary/aortic root or valves is required*
- * Acquisition protocol, contrast timing, contrast volume and the site of venous access needs to be modified on case-to-case basis based on underlying pathology*

Summary protocol parameters for cardiac CT studies.

	CT Calcium Score	CT Coronary Angiography	Cardiac CT for CHD	
			ECG Gated	Non ECG Gated
Tube Voltage (kVp)	120	100-120*	70-120*	70-120*
Reference Tube Current (mAs) with Modulation (AEC)	80	350-500*	70-200*	80-200*
ECG Gating	Prospective^	Prospective/ Retrospective with dose modulation, retrospective	Prospective, retrospective with dose modulation, retrospective	No
Pitch	N/A	0.2-0.4 in retrospective gating	0.4-0.6 in retrospective gating	1-1.2
Rotation speed	Fastest	Fastest	Fastest	Fastest
Collimation	Widest allowing for 3 mm reconstruction	Lowest possible	Lowest possible	Lowest possible
Slice thickness	3 mm	0.5-0.625 mm	0.5-1 mm	0.5-1 mm
Coverage	Tracheal bifurcation to bottom of heart	Tracheal bifurcation to bottom of heart	Arch of aorta to bottom of heart (Dual run protocol)	Thoracic inlet to bottom of kidney
Matrix	512 x 512	512 x 512	512 x 512	512 x 512

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