A Brief Review of CT Coronary Angiogram

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Introduction

Helical computed tomography (CT) started in the years of 90, enabled faster scan acquisition and faster data reconstruction. Multislice CT (MSCT) is the latest technology in this decade, functioning by acquiring multiple simultaneous slices using multi-detector system. Most advanced and contemporary models are the 64-slices machine, dual source CT machine and the 256-slices machine. The last-mentioned machine model, which is still on-trial, will be coming to the market soon. All these machines are competing for better performance by improving the spatial and temporal resolution. To date, a good CT machine can complete the scan in less than 10 seconds in optimal settings.

Indication for CT Coronary Angiogram

Framingham risk stratification alone is unable to confirm coronary artery disease. Other functional tests have the sensitivity and specificity of about 70-80% in detecting ischaemic heart disease. Compared with invasive coronary angiography for detection of significant lesions, segmental based sensitivity, specificity, and positive and negative predictive value of MSCT are 95%, 98%, 87% and 99% respectively (JAMA 2006; 293:2471-2478). General indications of CT Coronary Angiography are the asymptomatic patients with 2 or more cardiovascular risk factors, diabetic patients, patients without typical chest pain but abnormal treadmill stress test, post-CABG patients to assess the graft, patients with acute chest pain at the emergency department and those with anomalous coronary arteries.

Patients who are NOT considered for cardiac CT imaging are those with typical angina and strongly positive treadmill test, patient with renal dysfunction, known allergy to contrast media and young patient without any coronary risk factors.

The ACC guidelines suggest that screening for calcification may be of value for an individual who is considered to be at intermediate 10 year risk which is defined as a 10% to 20% likelihood of a cardiac event within the next 10 years (Circulation 2000).

Another role of cardiac CT is for RF (Radiofrequency) ablation planning. CT helps to provide a clear and accurate anatomy prior to ablation, especially in atrial fibrillation ablation. By integrating the CT images and Mapping system, it allows precise and shorter time of ablation.

CT is also useful in defining the coronary sinuses anatomy prior to CRT implantation.

Physical Principle and Practical Issue

Scan resolution

The 16/64 slices CT machine with narrow scan collimation provide reconstructed data that are isotropic. An isotropic voxel is a cube measuring the same x, y and z planes. That means an identical spatial resolution in all planes. This property significantly enhances the reconstruction work of CT Coronary Angiogram.

Radiation dose and Risk

As the number of slices increase, radiation efficiency also increases. Radiation dose is affected by mAs (electric current of the machine) and kVp and both have to be kept as low as possible. The radiation doses of coronary angiogram by a 16-slice and 64-slice CT machines are approximately 8-10 mSv and 13-18 mSv respectively. (Hunold et al Radiology 2003, Raff et al Jacc 2005)

Radiation risk of 14mSv is about 0.07% life time risk for inducing fatal cancer.

The risk of developing severe allergic reaction with non-ionic contrast is about 0.2%-0.7% of patient. Please be reminded that the background radiation dose that we receive each year from the sun and soil is about 3-4mSv and is indeed equivalent to about 300 chest radiographs. Single CT coronary angiogram is about 3 to 6 times the yearly radiation dose.

Spatial Resolution

A good spatial resolution is important as we are scanning coronary arteries which have diameter between 1mm to 4mm. To differentiate a 10%-20% coronary stenosis, we need an isotropic spatial resolution of at least 0.3mm or less. The spatial resolution of about 0.33-0.35mm is obtained by a 64-slice machine, with the isotropic voxel geometry of 0.5mm, and seems to be working good!

Temporal resolution

In order to image the rapid cardiac cycle, we need a good temporal resolution. Similar to photography, shorter temporal resolution means that we can catch the image at an almost frozen motion. Ideal temporal resolution should be less than 50msec. Better temporal resolution can be achieved by faster gantry (CT machine) rotation.
However it is eventually limited by the mechanical factors, and related to the weight of the whole machine. Other method to improve the temporal resolution include segmental/multi-segmental reconstruction with ECG Gating and more recently, the dual source CT technique. The retrospective ECG Gating algorithm/retrospective data reconstruction can further deal with the challenge of rapid cardiac motion.

**Beta Blockers**

The purpose of using beta blockers is to decrease the heart rate, so as to improve the temporal resolution. It also lowers the cardiac motion, lowers the cardiac output and therefore improves the contrast enhancement of the coronary arteries. Ideally the heart rate suitable for imaging should be less than 75bpm and being optimal at about 65bpm. We should be aware of the side effects and contraindications of beta blockers.

**Breath hold**

Purpose of breath holding during the scan is to reduce motion artifacts related to breathing. It is no longer a challenge nowadays using the 64-slice machine, and we need patients to hold their breath for less than 10 seconds. Breath holding period will be even less for more advance machines like dual-source or 256-slice machine. Actually longer breath holding may have influence to the heart rate.

**Contrast Media and Injection Design**

Non-ionic water soluble contrast (370mg/ml concentration) is used for injection, usually at right upper limb (providing short pathway towards the heart), preferably at the antecubital vein, to facilitate a higher injection rate of 4ml/sec. Good washout of contrast from the right heart can be achieved by saline chaser, and further hastens arrival of contrast and increases the peak enhancement by 30%.

The design of Dual-Flow Contrast Injection helps the Cardiac Function Analysis by improving the right heart visualisation.

**Post-acquisition Data Processing**

Under the property of retrospective ECG gating, different segments of data are available for reconstruction. The principle is to select the best imaging quality for a particular coronary artery at a specific segment. That is to review various segments for a particular vessel, apply the appropriate filter and window setting.

The tools of post-processing include Maximal Intensity Projection (MIP), Volume Rendering (VR) (Figure 1 & 2), Curve Planar Reconstruction (CPR) (Figure 3 to 6) or Multiplanar Reconstruction (MPR), 3D and cine loop. Radiologist or Cardiologist can apply different tools in the processing for each vessel.

**Clinical application**

**Calcium scoring**

Basic assumption is that the calcium load is proportional to the atherosclerotic plaque burden in the coronary arteries. It is well known that coronary artery calcification is a reliable sign of chronic atherosclerotic change and the calcified plaque is not amorphous or dystrophic calcification. High calcium scores pose an extremely elevated risk of hard cardiac events (Wayhs et al Jacc 2002:39:225) and therefore helpful in risk stratification. There is a strong prognostic value of calcium scoring (Guerci A, JACC 2003). Calcium scoring also has a role in monitoring therapy for those patient who are taking lipid lowering therapy or statin (Circulation 2002: 106:1077-1082). However the pitfall is that absence of calcium does not imply absence of atherosclerosis.

Methods of calcium load assessment include the Agatston score, volume scoring and mass scoring.

**Assessment of Coronary Stenosis**

There are methods to assess stenosis, including eye-balling which is a qualitative assessment, direct measurement on cross-section MPR or long axis MIP, and using automated vessel analysis software programme. The latter two are quantitative methods.

Most studies used a threshold of 50% luminal stenosis to define clinically significant stenosis, while the coronary flow reserve is not affected till the lumen is narrowed by 70-75%. The low threshold of 50% luminal narrowing decreases the likelihood of failing to identify patients in whom cardiac catheterisation is needed. Each stenosis should be assessed in at least two orthogonal views, and only the lumen is compared but not the wall.

In general CT tends to over-estimate the degree of stenosis due to the exaggerated partial volume averaging effect in order to assess the small-sized coronary arteries (Am J Cardiol 2005;96:784-787, JACC 2005;46:552). Other factors contribute to the difference are the difference in measurement techniques and difference of inter-observer agreement on estimation.

**Imaging of Bypass Graft**

Arterial grafts can be harvested from the left internal mammary artery (LIMA) connecting to the left anterior descending artery (LAD) or from the inferior epigastric artery to the right coronary artery (RCA). On images, the multiple metallic clips are the hints of previous grafting. Venous grafts are usually connecting from the ascending thoracic aorta to the LAD, Diagonal branch or obtuse marginal branch etc. Graft is usually well seen due to be relative less cardiac motion artifacts. We do need to be aware of the rather high location of origin of graft, eg. LIMA graft. For the totally occluded graft, the graft is not well visualised since no luminal contrast is present, and we can only see the graft nipple which is the origin of the graft. Graft stenosis is usually well assessed due to its little motion artifact.

**Imaging of Stent**

Restenosis is still a major hazard and CT Coronary Angiogram is able to assess patency. In general stent which is made of tantalum and gold will produce more blooming artifact. Strut thickness, and of course the size of the stent, play important role by producing more blooming artifact. Larger size with relative less percent of strut thickness will enable better visualisation of the lumen. Using a more sharp Reconstruction Kernels may improve stent visualisation.
Stent occlusion is relatively easy to diagnose when the stent lumen appears darker than the enhanced vessel lumen proximal to the stent, associated with absence of enhancement in distal vessel lumen.

Instent stenosis is suspected or considered if there is a dark rim inside the stent and the luminal diameter is reduced by more than 50%. This diagnosis can confidently be made by the 64-slice detector machine for stent larger than 3mm calibre.

**Practical Tips**

Setting up one’s routine when reviewing the images would be very useful. Try to use the tools available (VR, MIP, MPR/CPR) to review each artery. Look at the calcium score, you may need to give up some arterial segments which are heavily calcified. Beware of arterial calcification.

Stenosis has to be reviewed by different orthogonal planes before establishing the diagnosis. Grade the stenosis by luminal narrowing, and not to be influenced by the plaque, in order to avoid over estimation. In reverse, if there is no plaque, think about whether there is really a stenosis. Usually 70-75% are the best segment for slow heart rate, but try to review other segments if a lesion is suspected.

**Prospective**

**Cardiac Function Analysis**

By producing cardiac MPR images, the cardiac functional analysis can be done by software. The size or volume of the heart chambers can be measured at respective cardiac phase and the ejection fraction can be calculated. Cardiac wall motion can be analysed at a particular plane at a particular phase of the cycle and therefore any focal wall motion defect can be depicted. Studies have shown some good correlation between the CT and MR concerning the left ventricular (LV) function analysis (Radiology 2004:230 403-410); but the LV volume seems to be significantly higher, and ejection fraction and cardiac output be estimated significantly lower by Cardiac CT as compared with MRI in another recent finding (ECR 2006), related to the use of beta-blocker.

**Myocardial Perfusion using MSCT**

Studies are in progress and mostly on animal models. Results of MSCT are comparable with MRI in detection and sizing of myocardial infarction. However work needs to be done on stress induced myocardial ischaemia.

**Plaque Imaging**

MSCT can detect both soft plaque and calcified plaque and this is better than conventional cardiac catheterisation. Studies have shown that MSCT is not as good as Intravascular ultrasound (IVUS) in assessment of plaque volume (JACC 2005 46:147-154). However the CT may be helpful in characterising the plaque nature by assessment the density. We are still working on accurate differentiation of high lipid content plaques from fibrous plaque; depiction of culprit plaque with high lipid content and classify those vulnerable plaques.