Indications of Cardiac Computed Tomography and Coronary Computed Tomography Angiography: A Review

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ABSTRACT

The non-invasive imaging modality of multi-detector computed tomography (MDCT) has dramatically evolved over the last ten years and that is due to hardware and software developments. The newer generation scanners allow increased spatial and temporal resolution that improves the clinical reliability giving further insights into the evaluation of coronary artery disease. Heart morphology imaging followed by studies of myocardial function and assessment of cardiac valves can be performed from the information derived from the data of the coronary artery examination. Also, the venous anatomy of the heart, coronary artery bypass grafts, stents and cardiac tumors can be imaged and evaluated when necessary. For the beneficial use of this method, entrance criteria for different patient groups need to be set in order to allow the most beneficial use of multi-detector CT.

INTRODUCTION

Non-invasive cardiac imaging by multi-detector computed tomography (MDCT) has evolved significantly over the last ten years. This evolution is based on hardware and software developments, the driving force being the coronary arteries. The newer CT scanners, 64–slice, 256-slice, 320-slice and dual-source scanners, have improved the capabilities through increased temporal resolution (rotation speed) and improved spatial resolution (higher quality images). The results of many studies show that computed tomography coronary angiography (CTCA) with modern equipment has higher technical robustness and increased clinical reliability, allowing for new insights into the evaluation of coronary artery disease. Additional information concerning cardiac morphology and function is also available when necessary. The evaluation of non-stenotic coronary atherosclerotic plaques, coronary artery stents, bypass grafts, the assessment of ventricular and valvular function, cartography of pulmonary veins and the heart with the large vessels is possible in most situations. Knowledge and application of the proper indications should be applied at all times.

The clinical impact of the new technology includes the improvement in image quality in terms of spatial and temporal resolution. The improvement in spatial...
resolution increases the ability to visualize small diameter vessels, to quantify calcium as it reduces blooming artifacts, enables the reduction of blooming artifacts in stents and improves the definition of the presence of coronary plaques. The improvement in temporal resolution increases the ability to freeze images in the cardiac cycle and enables additional reconstruction windows to be found within the cardiac cycle and reduces scan time.3,4

Cardiac CT imaging is based on continuous spiral scanning of the heart so that all of the phases of the cardiac cycle are included in the examination. The use of ECG-gating allows for retrospective reconstruction of the images in any phase of the cardiac cycle that is chosen in order to be evaluated, usually the phase with less motion. These retrospective images also permit the assessment of cardiac function due to the data collected at different phases of the cycle as aforementioned.4,5

With the latest MDCTs, data acquisition is performed in a single breath hold of about 5-10 seconds. The injection of contrast media is synchronized with the use of injectors, monitored by bolus tracking techniques. The mode for optimal enhancement after contrast delivery is automated bolus tracking. A pre-monitoring scan is performed within the target volume to localize the target vessel for contrast timing. A region of interest is placed in the target vessel and Hounsfield values are continuously measured during injection of the contrast media. When the trigger threshold is reached (130-140 HU), the spiral scan is initialized automatically. The amount of contrast media used in a typical exam is 100 ml, high concentrations of iodine are preferred, 350-400 mg/ml. It is important that a patent antecubital vein is used for a continuous high flow rate of contrast medium at 4-6 ml/s.2,3

The acquired data are reconstructed to produce image data sets for evaluation. For low heart rates the best phase of the cycle is the mid to end-diastolic phase and for high heart rates the end-systolic phase produces better images. Heart rhythm variability influences image quality even with the latest MDCT scanners. Many centers administer β-blockers one hour before the examination in order to lower the heart rate and achieve vasodilatation to obtain better images. Other centers administer nitroglycerin sublingually for vasodilatation of the coronaries, which not only permits better visualization of the coronary arteries but also and most importantly, it decreases the possibility of falsely diagnosing sites of vasospasm as stenoses.

Radiation is a major concern during the last few years and newer examination techniques are performed in order to lower the effective radiation dose. The effective radiation dose for a typical examination of the coronaries is between 5 and 20 mSv. The techniques performed are tube current modulation which lowers the tube current during diastole, reduction of tube voltage when possible especially in thin patients, step and shoot approach, which concerns a non-spiral approach with the table remaining stationary and the tube rotating around the patient. In many reports these methods show a major reduction in the radiation dose.6,7

CORONARY ARTERY IMAGING

STENOSIS

Due to the limited spatial and temporal resolution of the first scanners, only the proximal coronary arteries were visualized and assessed and 25% of the segments were not evaluated due to unsatisfactory images. The latest CT scanners with improved speed and image quality permit the visualization of all the coronary segments. Classification follows the modified American Heart Association classification. The sensitivity in detecting coronary artery stenoses increased from 84% for 4-slice CT to over 93% in the latest CTs and the specificity from 93% to over 96%. Approximately up to 23% of all segments cannot be assessed by the 16-slice scanners and up to 12% by the 64-slice scanners, usually concerning small branches and distal segments in the latest scanners. The negative predictive value was high in all reports which indicated that the method may be used as a non-invasive exam to rule out significant coronary artery disease (Figures 1-3).8,9

Reports concerning dual-source CT technology show a better visualization of distal segments even in patients with high cardiac rates without the administration of beta blockers. The 256-slice CT scanners allow imaging of the heart in a single cardiac cycle, making the modality less susceptible to arrhythmias. Another factor influencing image quality is

FIGURE 1. Multiple image projection of a patent LAD (arrow). LAD = left anterior descending (coronary artery).
artery calcifications which cause significant limitations in the evaluation of the percentage of stenosis, even with the newer CTS. Calcification leads to overestimation of stenosis in most instances. Another limitation of the examination is that functional relevance of stenoses is not provided, only anatomical. Different studies performed make clear that stenoses do not lead to abnormal perfusion in all cases. Patients with obstructed arteries on MDCT have shown that only half of them had abnormal single photon emission computed tomography (SPECT) or positron emission tomography (PET) studies. Sixty-four slice MDCT is a reliable modality to rule out functionally relevant coronary artery disease (CAD) in a non-selected population with an intermediate pre-test likelihood of disease; an abnormal CTCA does not necessarily predict ischemia.\textsuperscript{6,12}

Hybrid modalities provide information concerning functional and anatomical information such as PET/CT with a sensitivity of 90\% and a specificity of 98\% in detecting hemodynamically significant coronary stenoses. Studies concerning SPECT/MDCT in evaluation of significant stenoses and reversible perfusion defects in the same anatomical region yield a high diagnostic accuracy. Sensitivity, specificity, positive predictive value and negative predictive value of MDCT were 96\%, 63\%, 31\% and 99\% respectively; the respective values for SPECT/MDCT were 96\%, 95\%, 77\% and 99\%.\textsuperscript{13}

Studies of MDCT have been performed in specific clinical scenarios, such as in patients referred for valve surgery, dilated cardiomyopathy, and left bundle branch block with very high positive predictive value and negative predictive value, from 80\%-93\% and 97-100\% respectively. Acute chest pain is another situation under which the modality has been tested, concerning patients in the emergency department with negative initial biomarkers and absence of ischemic ECG changes. Studies report a 100\% negative predictive value with low positive predictive value of 47\%.\textsuperscript{14-16}

The clinical application of CTCA is to detect or rule out coronary artery stenoses and should be recommended in patients with a low to intermediate risk of CAD in order to establish or exclude it. The evaluation of prognosis and risk stratification for cardiac events is essential to decide on the proper management and to select patients for conventional coronary angiography. Studies suggest that CTCA provides independent prognostic information that may be useful for the prediction of cardiac events in patients with known or suspected CAD at 1-year follow up. Other studies report that CTCA suggests an incremental prognostic value over traditional risk factors assessment and coronary calcium score.\textsuperscript{3,9-11}

**CORONARY PLAQUE IMAGING**

Coronary plaques are defined as structures larger than 1 mm within and/or adjacent to coronary artery lumen which
are distinguishable from the vessel lumen and surrounding pericardial tissue. Obstructive coronary plaques are defined as plaques resulting in greater than 50% luminal narrowing; non-obstructive plaques are defined as plaques that result in 50% luminal narrowing or less. The type of plaque is classified as, a. non-calcified, which is a plaque with a lower density compared with the contrast-enhanced vessel lumen; b. calcified plaque, which is a plaque with a high density >130HU and; c. mixed plaque, which is a plaque with non-calcified and calcified areas.17

Coronary calcium is a surrogate marker for the presence of coronary atherosclerotic plaque. MDCT allows the detection and quantification of coronary artery calcium. The Agatston score, which is most frequently used, takes into account the area (in mm²) and the CT density (Hounsfield units) of calcified plaques. The amount of calcium correlates closely to the overall atherosclerotic plaque burden. Coronary calcium is detected in the vast majority of patients with acute coronary syndromes, and the amount of calcium is quite higher than in matched control subjects without CAD. As with stenoses, calcification is not always associated with hemodynamically significant luminal narrowing, so asymptomatic subjects should not be referred for selective coronary angiography, even with the presence of large amounts of calcified plaques (Figure 4).3

The contribution of calcium evaluation to risk stratification can be expected in subjects that have an intermediate risk for coronary pathology on the basis of risk factors such as the Framingham score. Screening of the population or self-referrals are not recommended, even though the radiation dose is low, 1-2 mSv. Studies have not shown yet that there is a link between the progression of calcium and cardiac events. In addition to that, studies concerning the amount of calcium and the influence of lipid lowering medications are non homogeneous; one reason is the variability of calcification measurements (Figures 5 & 6).3,17

Non-calcified coronary artery plaques can also be detected by MDCT. The CT density within fibrous plaques is higher than lipid plaques but there is a high variability of measurements which does not allow accurate classification of non-calcified plaques. Data concerning the prognosis of plaques and the application of CT are few. Small retrospective studies concerning the investigation of plaque characteristics in patients with CAD in comparison to patients with stable angina showed that positive remodeling and spotty calcification were significantly more frequent in the acute coronary syndromes. Characteristics of plaques associated with acute coronary syndromes include low plaque density and spotty calcification. Large calcifications were more frequent in stable lesions. One analysis concerning patients that were followed after being examined by CT, demonstrated a higher cardiac event rate with non-obstructive plaques compared with subjects without any plaques.18,19

There is a potential value of plaque imaging by MDCT for risk prediction but more studies need to be performed and we should keep in mind that plaque imaging requires the highest quality of images. Currently the clinical application of MDCT for this purpose in asymptomatic patients is not feasible.

FIGURE 4. Calcified plaque in proximal LM (arrow) that does not cause lumen stenosis. LM = left main (coronary artery).

FIGURE 5. Axial image of the heart at the level of the origin of the LM ostium. Mixed plaque in proximal LAD with lipid and calcified components causing a stenosis of 50% (arrow). Small calcified plaque in LM. LAD = left anterior descending (coronary artery); LM = left main (coronary artery).
CORONARY ARTERY BYPASS GRAFTS

Grafts can be visualized and their patency can be evaluated with a very high diagnostic accuracy because they have a larger diameter than the native coronary arteries and do not move as fast. Surgical clips often cause significant artifacts that impair visualization and evaluation of the degree of stenosis especially at the sites of anastomosis. When examining an operated patient it is important to assess the grafts, the distal runoff and the non-grafted arteries, which are difficult in many cases because of impaired image quality, due to significant calcifications of the native arteries. Studies report a low accuracy in evaluating native arteries in patients with bypass grafts, with a sensitivity of 79-100%, specificity of 59-89%, negative predictive value of 97% and a positive predictive value of 67%. The clinical application of MDCT in patients with bypass grafts should be limited to cases in which only bypass evaluation is needed and in cases that angiography failed to evaluate or image a graft. Also, in the acute setting of chest pain in patients with bypass grafts, assessment of graft patency may be necessary (Figures 7 & 8).20-22

CORONARY STENT IMAGING

Stents are characterized by a high density which at CT causes an enlargement of the image due to the blooming effect. This artifact is produced by beam hardening and interpolation. The use of 16-slice scanners improved the visualization of stents and in-stent stenosis (reduction of the in-stent lumen >50%). The 64-slice scanners show a higher diagnostic ac-
curacy with high sensitivity and specificity of 91% and 98%, respectively.

The selection and inclusion criteria of patients should be rigid and aimed at providing reliable findings. Studies are recommended to be performed on patients with a heart rate of <70 bpm and sinus rhythm, on stents with a diameter >3 mm implanted in proximal segments of the coronary tree (Figure 9).23,24

**CORONARY ARTERY ANOMALIES-CONGENITAL HEART DISEASE**

Coronary artery anomalies are uncommon with a prevalence of 1%. Early detection and evaluation of such anomalies is essential because of their potential association with myocardial ischemia and sudden death. An overall three-dimensional image of the heart and coronary artery tree allows for the detection and definition of vessel anomalies and their relationship to other nearby anatomical structures. The method has been used to identify such conditions because invasive angiography is not always successful; the diagnostic accuracy of MDCT is about 100% in such cases.

Children and adults with congenital heart disease can be examined with MDCT because of its high spatial and temporal resolution. Reports state the successful preoperative assessment of tetralogy of Fallot, coarctation of the aorta, patent ductus arteriosus and follow up of shunts and baffles especially when echocardiography does not provide enough information and when magnetic resonance imaging (MRI) cannot be performed as when pacemakers or defibrillators are present (Figure 10).25

**NON-CORONARY IMAGING**

**LEFT AND RIGHT VENTRICULAR FUNCTION**

Data sets concerning functional parameters of the heart such as left and right ventricular function, stroke volume, ejection fraction, and myocardial mass can be calculated from the CT angiography examination performed, since fast and sophisticated workstations exist today (Figure 11). Studies have shown that the results from MDCT correlate well with other imaging modalities such as MRI, echocardiography, and SPECT. Usually the differences concern the estimation of left ventricular volumes (end-systolic, end-diastolic) by MDCT. The clinical relevance of these differences is of no importance. These functional data have also been used in situations concerning pulmonary embolism, congenital heart disease and atrial septal defect with accurate findings compared to other methods.26

**MYOCARDIAL VIABILITY AND PERFUSION**

MDCT evaluates myocardial viability the same way MRI
does by studying late enhancement. In a situation of myocardial infarction, acute, sub-acute and chronic myocardial perfusion defects can be seen in the early phase of contrast enhancement. About 5-15 minutes post-contrast infusion, late hyper-enhancement of infarcted areas can be visualized. Studies have shown that late enhancement shows excellent agreement with infarct size and location. Pre-clinical and preliminary clinical studies have documented that MDCT can evaluate myocardial perfusion; MDCT exams when performed during adenosine infusion allow semi-quantitative measures of myocardial perfusion. Preliminary clinical evidence suggests that this method when applied to patients with a high risk for CAD may be capable of detecting early perfusion defects in areas of the myocardium supplied by arteries with obstructive atherosclerosis.

Recommendation of clinical use of MDCT for perfusion and viability can not be allowed due to limited clinical data as of now.

VALVULAR HEART DISEASE

Direct planimetry of the aortic valve area is performed for the evaluation of aortic valve stenosis with a very high accuracy rate according to different studies. When compared to echocardiography the sensitivity was 100% and specificity 93.7%, positive predictive value and negative predictive value 97% and 100% accordingly on a 16-slice CT scanner.

Several studies have demonstrated that MDCT provides functional information regarding valvular disease severity. Planimetric measurements of maximal opening and maximal regurgitant orifice areas of the mitral and aortic valve have shown to yield information that is similar to quantitative hemodynamic information derived from echocardiography. The major advantages of CT over echocardiography with regard to valvular morphology and function evaluation are the lack of operator and patient morphology dependence and the lack of acoustic shadowing in association with valvular calcifications. The major disadvantage of CT is the radiation exposure which prevents the repeated assessment of patients (Figures 12, 13).

Other studies report the detection of valvular abnormalities, thickened mitral leaflets, presence of mitral annulus calcification, and leaflet calcification. When compared to echocardiography, agreement was reached in 95-100% of all cases.

Clinical data are also limited in this case, thus recommendation for the use of MDCT for the evaluation of heart valves applies in specific patient subsets.
CARDIAC & CORONARY CT

Figure 13. Virtual endoscopic image of aortic valve calcifications with a >50% stenosis.

PULMONARY VENOUS ANATOMY

Ablation procedures are performed with an increased rate in patients with drug refractory atrial fibrillation. MDCT provides detailed anatomical mapping of the pulmonary veins and atria through high resolution three-dimensional and axial images of the heart. By visualizing surrounding structures, MDCT helps to reduce complications according to different reports allowing for safer and more successful ablation procedures.

Table 1. Appropriate Clinical Indications for the use of CT Coronary Angiography

| 1. Detection or exclusion of CAD in individuals with ambiguous results of previous tests: uninterpretable or equivocal stress test, intermediate pre-test probability of CAD, uninterpretable ECG or inability to exercise. |
| 2. Detection or exclusion of CAD in patients with acute chest pain: Intermediate pre-test probability of CAD, absent ECG changes, negative serial enzymes. |
| 3. Detection of CAD in symptomatic patients: evaluation of intra-cardiac structures, detection of suspected coronary anomaly. |
| 4. Structure and function-morphology: evaluation of complex congenital heart disease, including anomalies of coronary circulation, great vessels, and cardiac chambers and valves (Figure 15). |
| 5. Structure and function evaluation of intra and extra cardiac structures: assessment of a cardiac tumor or thrombus, evaluation of pericardial pathology, patients with technically limited images from echocardiography, MRI, or trans-esophageal echocardiography. |
| 6. Patients with technically limited images from echocardiogram, MRI, or trans-esophageal echocardiography: evaluation of pulmonary vein anatomy prior to ablation, coronary vein mapping prior to placement of biventricular pacemaker, coronary artery mapping including internal mammary arteries prior to repeat cardiac revascularization. |
| 7. Structure and function evaluation of aortic and pulmonary disease: evaluation of suspected aortic dissection or aneurysm of the thoracic aorta, suspected pulmonary embolism (Figure 16). |

CAD = coronary artery disease; CT = computed tomography; ECG = electrocardiogram; MRI = magnetic resonance imaging

Advanced image integration systems allow for the use of real time anatomy through data acquired from the CT exam during the procedure in order to help the cardiologist deal with complex cardiac arrhythmias. A known late complication of ablation is stenosis of pulmonary veins. MDCT has shown to be effective in imaging such stenoses successfully. MDCT can be recommended for anatomical mapping of the pulmonary veins before ablation procedures are performed.29,30
CARDIAC TUMORS

MDCT can locate, differentiate, confirm or exclude the presence of a cardiac mass and is thus regarded essential for adequate mapping and staging. Additionally, it provides simultaneous detailed information of the heart, mediastinum and lungs allowing for proper therapy planning (Figure 14).31,32

The currently recommended appropriate clinical indications for the use of CT coronary angiography are described in Table 1. The worldwide acceptance of MDCT coronary angiography requires further studies and technological development to ensure optimal test results and a guided management of CAD. Hybrid PET/MDCT may offer the opportunity for non-invasive evaluation of the presence of CAD and its consequences in the coronaries and myocardium.

REFERENCES


