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Review Article

Cardiac Multidetector Computed Tomography: Where Do We Stand?

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Significant advances in medical technology have made noninvasive cardiac imaging more effective and appealing. This review will describe recent technical developments in cardiac computed tomography (CT) and will evaluate current and potential clinical applications.

History

Multidetector-row CT (MDCT) scanners for the noninvasive detection of coronary artery disease (CAD) were introduced in 1999, with the 4-slice scanners that allowed small and rapidly moving structures like the coronary arteries to be visualized with sufficient image quality.[1] Soon, the technology advanced further, with the introduction of 16-, 40-, and 64-slice scanners (current systems) and prototype 256- and 320-detector-CT. The new generation of 64 MDCT scanners permitted greater patient coverage per gantry rotation and thus a shorter scan time. Breath-hold time with the current 64-slice scanners is 5-10 s, resulting in less patient discomfort and fewer artifacts induced by respiratory motion or heart rate variability. The shorter acquisition time allows the use of smaller volumes of intravenous contrast material (90-100 ml) and reduces radiation exposure. Recently, dual-source MDCT scanners were launched, having two pairs of X-ray sources and multislice detectors mounted at 90° to each other.[2] This technology allows faster scanning and achieves a temporal resolution of 83 ms, thereby limiting motion artifacts caused by rapid heart rates, a problem faced by single source scanners, which required beta blockade in patients with heart rates >65 bpm. Table 1 illustrates the effect of multiple slices, faster rotation time and dual-source technology on spatial and temporal resolution.

Data acquisition

Retrospective ECG gating

Cardiac CT is achieved by continuous, low pitch, spiral scanning (table feed/gantry rotation), with the patient moving at a constant speed through the gantry. This results in oversampling of information across different phases of the cardiac cycle and across several consecutive heart beats. The ECG is recorded simultaneously, allowing retrospective reconstruction of images at any desired phase of the cardiac cycle (usually the one with least cardiac motion). The actual phase used for data reconstruction, quoted as a percentage of the RR interval (e.g. 70%) or absolute time (e.g. 350 ms), can vary for each coronary artery or each coronary segment. Another advantage of retrospective gating is that it permits the reconstruction of data sets at multiple time instants during the cardiac cycle, thereby allowing "dynamic imaging" and functional analysis.

Table 1. Spatial and temporal resolution.

	Spatial resolution (mm)	Temporal resolution (ms)
Invasive angiography	0.2	5-20
16-slice CT	0.5-0.7	200
64-slice CT	0.4-0.6	165
Dual source 2 × 64 slice CT	0.4-0.6	83
Magnetic resonance angiography	0.7	20

On the other hand, during retrospectively ECG-gated spiral imaging of the heart, data are acquired with a small spiral pitch and continuous X-ray exposure at the expense of a higher radiation dose for the patient. Retrospective ECG gating is represented schematically in Figure 1a.

Prospective ECG triggering

With this technique, the R wave is used to trigger the CT scan with a user selectable, predefined time delay. This is a non-spiral scanning mode, with the table remaining stationary while data are acquired. When data acquisition is completed for one location, the table is advanced to the next location for a subsequent scan. This technique has the potential to greatly reduce radiation dose, but it is limited by the fact that a single ectopic beat or any kind of arrhythmia leads the scanner to start scanning when the heart is in a totally different position in the chest. Prospective ECG triggering is represented schematically in Figure 1b.

Scanning procedure

A large intravenous cannula is required for the contrast material injection. The best motion-free images are obtained at a slow heart rate, and for any scanner apart from dual source scanners it is essential to lower heart rate to <65 bpm. Usually, b-blockers are administered, orally or intravenously, but if the patient cannot tolerate b-blockers calcium channel blockers can be used. Nitroglycerin should be administered sublingually to achieve vasodilation and optimal opacification of the coronary arteries.[3] The physician should give the patient specific instructions about breath holding and should warn the patient about the warm feeling that is produced by contrast administration.

A scout X-ray (topogram) is performed to confirm the patient's correct position within the gantry. Usually, a prospectively ECG-triggered scan with 3 mm slice thickness is acquired before proceeding to the coronary angiogram, in order to quantify calcium (calcium score). The calcium score is derived from the product of the area of calcification and a factor determined by the maximal X-ray density within that area. The calcium score can be calculated per coronary segment, per coronary vessel or for the entire coronary tree. The start of the scan (using contrast material) should be synchronized with the arrival of contrast in the ascending aorta. One way to achieve this is the 'bolus tracking' technique, where the scanner detects the contrast's arrival in the region of interest by registering the increase in Hounsfield units (usually an increase of 100 HU) and the scan starts then automatically; another way is the 'test bolus' technique, where a small bolus of contrast is used to determine the venoarterial transit time. The total contrast volume is 90-100 ml (the iodine concentration of the contrast must be at least 350 mg/ml) depending on scanner type, heart rate, body mass index; the injection flow rate is 5-6 ml/s. Contrast material injection

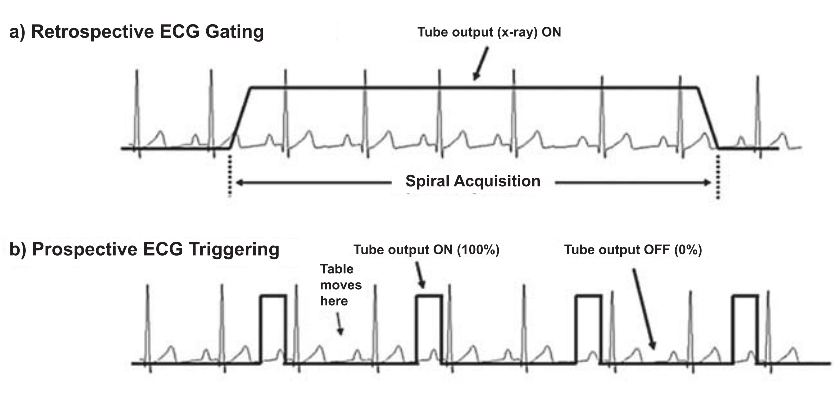

Figure 1. The concepts of data acquisition with retrospective ECG gating (a) and prospective ECG triggering (b).

is followed by saline flush injection at the same injection flow rate. Depending on each scanner's options, ECG-triggered tube current modulation techniques should always be used to reduce radiation dose (see "Radiation exposure" below). The whole scanning procedure is usually completed within 10-15 minutes (including patient preparation and actual scanning).

Image reconstruction

Image post-processing and reconstruction is the process of converting raw source data from the spiral scan into images useful to the observer. The large amount of data then needs to be reconstructed using retrospective ECG gating, in order to select the cardiac phase with the least motion (Figure 2). Typically the mid- to end-diastole is better for patients with low heart rates and the end-systole for patients with high heart rates.[4,5] The average heart rate, and especially heart rate variability, substantially influence image quality.[6] Different reconstruction algorithms or kernels are used to convert raw data into interpretable images. Generally, sharper (and thus noisier) kernels are used to reduce blooming artifact in the presence of significant calcification or stents (Figure 3). The retrospectively ECG-gated image data sets that are generated usually consist of 200-300 thin (0.5-0.75 mm) transaxially oriented slices. Those axial images are generally the most important for the detection of coronary stenoses, but further reconstructions are made to aid analysis. Reconstructions used are multiplanar reformation and maximum intensity projection (Figure 4). In multiplanar reformation (Figure 4a) a straight or a curved plane is defined and only the data in this plane are displayed; a vessel can be stretched out or viewed from different angles. The maximum intensity projection reconstructions (Figure 4b) display only the highest attenuation voxels taken from a slab through the three-dimensional data for each pixel in the resulting image. Volume rendering techniques give an accurate overview of the general coronary anatomy and they are mainly used for displaying bypass grafts and congenital coronary anomalies (Figures 5-6).

Radiation exposure

The effective radiation dose of a contrast-enhanced 64-slice cardiac CT scan is 12-20 mSv, whereas that of an invasive angiography is 3-4 mSv (or higher, depending on the physician performing the examination).[7,8] Nuclear perfusion scans have a typical dose of 8-25 mSv.[9] In our efforts to limit the radiation dose, we should keep the scan volume length and the tube current as low as possible. An effective way of reducing radiation dose is the use of ECG-triggered tube current modulation, where X-ray power is lowered during less important parts of the cardiac cycle (Figure 7). This technique can achieve an effective radiation dose reduction of up to 64%, especially at low heart rates and using dual-source scanners, with preservation of image quality.[10,11] Additionally, tube voltage can be reduced from 120 to 100 kV in patients with low body mass.[12] However, the most effective way of reducing radiation exposure is the use of prospectively ECG-triggered im-

Figure 2. The effect of reconstructions at different time instants during the cardiac cycle. In figure 2a (diastole) a patent stent is clearly demonstrated in the left anterior descending artery (LAD) and in figure 2b (systole) the image is non-interpretable.

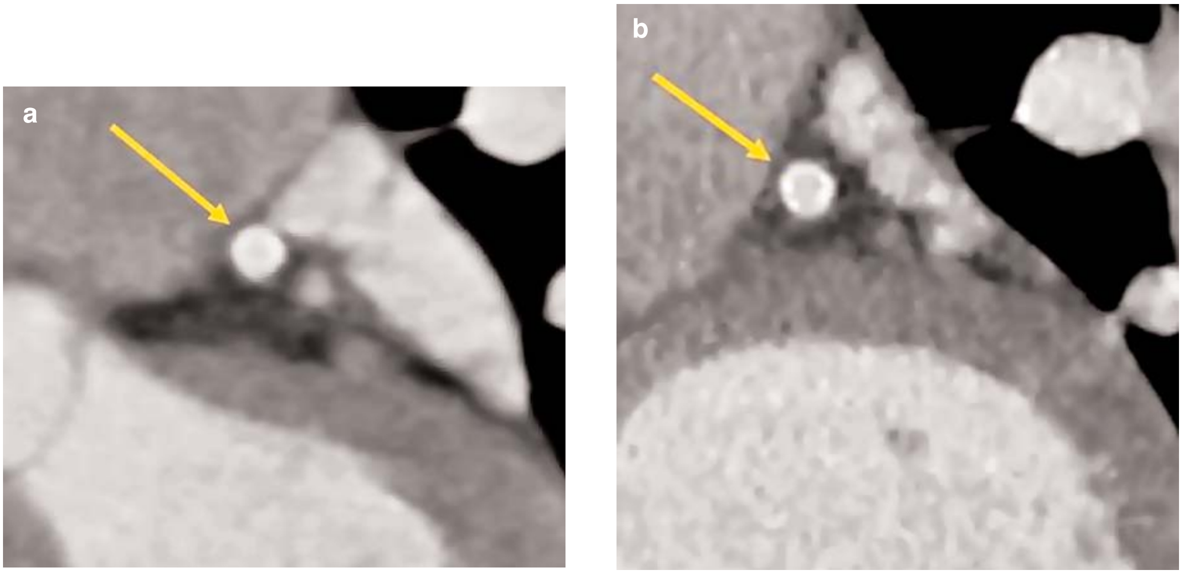

Figure 3. The effect of different reconstruction kernels on image quality: A cross-section of a stent in the left anterior descending artery (LAD) displayed with a smooth kernel (Bf26) in 3a and with a sharp one (Bf46) in 3b.

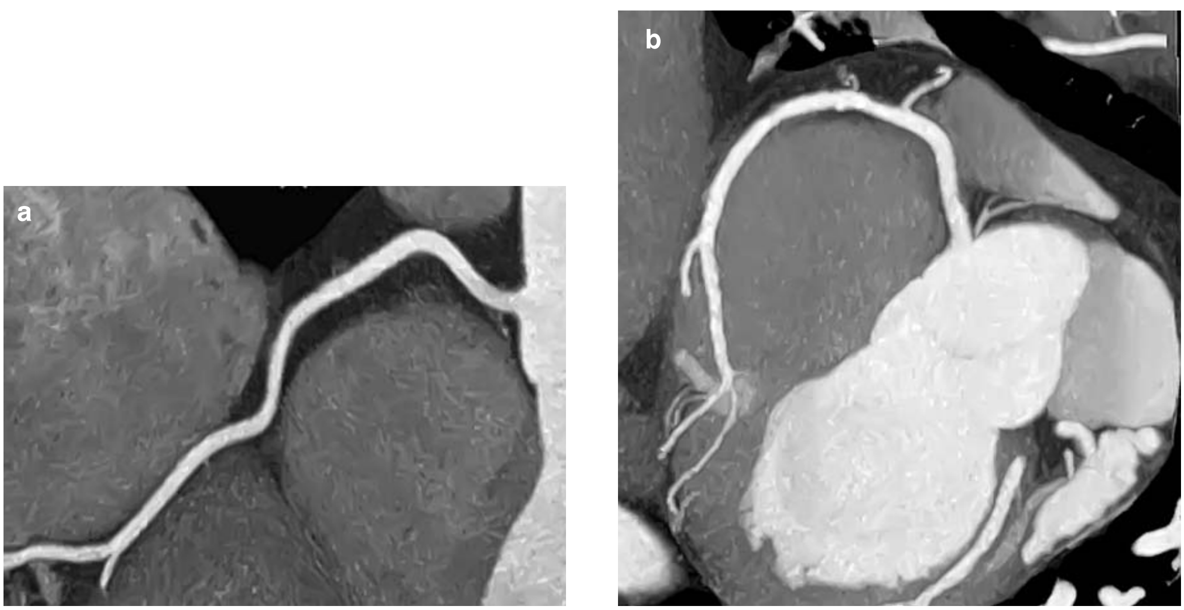

Figure 4. a: Curved multiplanar projection (MPR) of a right coronary artery (RCA). b: Maximum intensity projection (MIP) of the RCA.

age acquisition protocols, where very significant reductions in radiation dose have been reported (up to 2.8 mSv for males and 4.1 mSv for females), with the disadvantage that even small changes in the heart rate can cause acquisition in different heart phases, resulting in artifacts due to inconsistent volume coverage.[13-15]

Clinical applications

Coronary angiography

The greatest promise of MDCT lies in its capacity to provide a noninvasive alternative to conventional catheter-based coronary angiography. Diagnostic

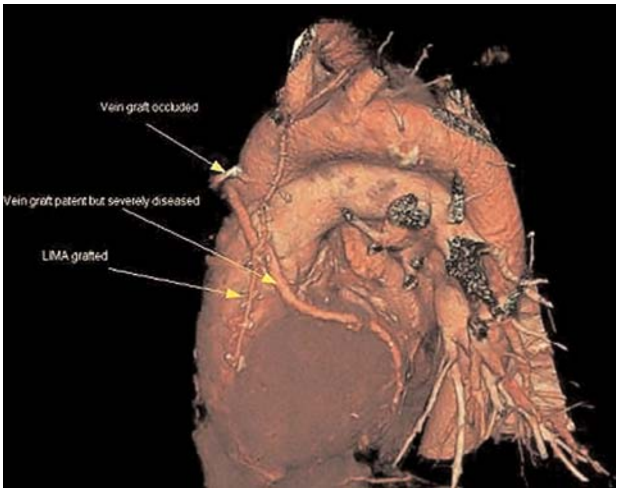

Figure 5. A grafted left internal mammary artery, a proximally occluded vein graft, and a patent but severely stenosed vein graft, displayed in the same image with the volume rendering technique (VRT).

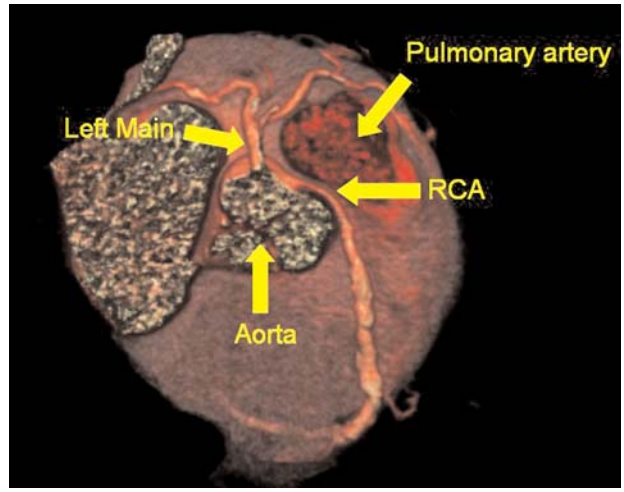

Figure 6. A case of 'malignant' course of the right coronary artery (RCA), which arises from the left coronary sinus and courses between the aortic bulb and the pulmonary artery, displayed with the volume rendering technique (VRT).

performance has significantly improved from the 4-slice to the 64-slice scanners. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) increased from 57%, 91%, 60% and 90%, respectively, with the 4-slice scanners to 99%, 96%, 80% and 100%, respectively, with the 64-slice scanners; perhaps more importantly, the number of coronary artery segments with poor image quality decreased from 33.1% to 2.6%.[16] A recent meta-analysis concerning the use of 64-slice CT technology demonstrated pooled sensitivity 99%, specificity 89%, PPV 93%, NPV 100% in patient based detection of significant CAD (defined as presence of >50% stenosis); in segment based detection the values were 90%, 97%, 76% and 99%, respectively.[17] Similar results were shown by two other meta-analyses concerning 64-slice scanners (Table 2).[18,19] The studies that were available until now were small single-centered studies from centers with great experience and expertise. Recently, the results of three prospective multicenter studies of the diagnostic performance of 64-slice CT coronary angiography became available (Table 3 summarizes the results of the multicenter studies).[20-22] The common finding of all these studies is the excellent NPV, which establishes the technique as an effective non-invasive alternative to invasive coronary angiography for ruling out obstructive coronary artery stenosis.

Limitations

Cardiac arrhythmias

Patients with tachycardia or irregular heartbeats (atrial fibrillation, ectopic beats) often provide non-diagnostic images and cannot be evaluated, although the higher temporal resolution of dual source-CT at least allows the assessment of patients with high regular heart rates.

Calcification

The image displayed on our monitors is made up of a series of three-dimensional pixels called voxels, the size of which depends on the scanner's spatial resolu-

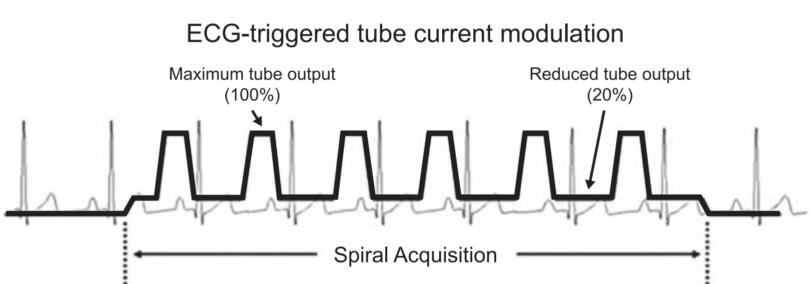

Figure 7. Spiral data acquisition with ECG-triggered tube current modulation. The technique allows retrospective gating within the boundaries of a window of maximum tube output.

Table 2. Diagnostic performance of 64-slice computed tomography for the detection of significant coronary stenosis on a per patient basis (meta-analyses).

Study	Patients	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Mowatt et al[17]	1286	99	89	93	100
Abdulla et al[18]	875	97.5	91	93.5	96.5
Stein et al[19]	2045	98	88	93	96

NPV – negative predictive value; PPV – positive predictive value.

Table 3. Prospective multicenter studies of the diagnostic performance of 64-slice computed tomography for the detection of significant coronary stenosis (>50% diameter stenosis) on a per patient basis.

Study	Patients	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Budoff et al[20] (ACCURACY)	230	95	83	64	99
Miller et al[21] (CORE 64)	291	85	90	91	83
Meijboom et al[22]	360	99	64	86	97

NPV – negative predictive value; PPV – positive predictive value.

tion. Each voxel displays a shade of gray (from black to white) depending on the average attenuation of the tissue. Calcium has high attenuation values and appears white, while fat or air with low attenuation values appear black. If a voxel within a coronary artery contains calcium and tissue with low attenuation (e.g. fat), the whole of the voxel will be displayed as white and significant information about the fat tissue will be lost. This is the 'partial volume effect'. The smaller the voxel size, the fewer partial volume effects will be seen, which underlines the need for increased spatial resolution. High temporal resolution is also important because high density artifacts are exacerbated by the presence of residual motion in MDCT data sets.[23] Another significant artifact caused by high density structures is the "blooming effect". The blooming effect results from beam hardening, where the energy spectrum of the X-ray beam increases as it passes through a hyperattenuating structure, because lower-energy photons are absorbed more rapidly than higher-energy photons, with the result that the beam is more intense when it reaches the detectors. Blooming leads to overestimation of the size of high attenuation objects (e.g. coronary calcification and stents). Both the partial volume and the blooming effect lead to underestimation of the lumen size, in other words to overestimation of the severity of the stenosis. Calcium scores >400 reduce specificity significantly.[20] The presence of heavy calcifications (which is often the case in the elderly or in patients with longstanding CAD) compromises image quality significantly and often makes some segments of the coronary tree uninterpretable.

Stents

The evaluation of stents is hampered by the occurrence of high-density artifacts (partial volume and blooming effect) caused by the stent struts. 64-slice scanners can identify in-stent restenosis in stents larger than 3 mm with good NPV, but a large proportion of stents cannot be assessed, which limits the wider clinical use of the method.[24, 25]

Table 4 summarizes the results of 64-slice MDCT coronary angiography in the assessment of stent restenosis.[25-30] Figure 8 illustrates the presence of a patent stent in the right coronary artery. Recent reports with dual-source scanners show better diagnostic performance, but false positive findings in stents <2.75 mm were still frequent.[31] MDCT coronary angiography cannot be recommended for the evaluation of small (<2.75 mm) stents.

Bypass grafts

Coronary artery bypass grafts (CABG) are less mobile, while saphenous vein grafts in particular have large diameters and are therefore easy to image with CT (Fig-

Table 4. Diagnostic performance of 64-slice computed tomography for the detection of in-stent restenosis.

Study	Patients/stents	Not evaluable (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Rixe et al[26]	64/102	42	86	98	86	98
Rist et al[27]	25/46	2	75	92	67	94
Oncel et al[28]	30/39	0	89	95	94	90
Ehara et al[29]	81/125	12	91	93	77	98
Cademartiri et al[25]	182/192	7	95	93	63.3	99.3
Manghat et al[30]	40/114	9.6	85	86.1	60.7	95.8

NPV – negative predictive value; PPV – positive predictive value.

ure 5). Occluded grafts and stenoses in the body of bypass conduits can be easily detected with excellent diagnostic accuracy.[32-34] Invasive coronary angiography can be more technically challenging in these patients, with larger contrast volumes and radiation exposure. Table 5 summarizes the results of 64-slice MDCT studies for coronary graft assessment.[32,33,35,36] However, native coronary vessels usually have extensive calcifications in post-CABG patients, making evaluation of distal runoff and non-grafted coronary arteries particularly difficult, and most studies report low accuracies.[35,36] Volume-rendered reconstructed images may be helpful when planning a redo bypass graft or percutaneous intervention.

Lesion severity

The limited spatial and temporal resolution of CT compared to invasive coronary angiography creates difficulties in assessing the severity of coronary artery stenoses. There is a tendency to overestimate luminal narrowing in MDCT compared to invasive angiography, especially in the presence of severe calcifications.[38,39]

Functional relevance

Coronary CT angiography (as well as invasive coronary angiography) provides only anatomical visualization of stenoses. Neither visual nor quantitative CT coronary angiographic assessments of the hemodynamic significance of coronary artery stenoses correlate well with the functional assessment of the severity of the stenoses as derived from fractional flow reserve.[40] In a recent comparison of MDCT with SPECT myocardial perfusion imaging, only 45% of patients with an abnormal MDCT (defined as at least one >50% stenosis) had a perfusion defect in SPECT,[41] demonstrating a significant mismatch between anatomy and function. Coronary CT and perfusion imaging give complementary information, provided by hybrid PET/CT or hybrid SPECT/CT techniques, that has shown encouraging results.[42,43]

Reimbursement

In many countries there is so far no formal recognition of the role of cardiac CT, leading to funding problems.

Coronary vessel wall-plaque imaging

Calcium scoring

Coronary calcium is a surrogate marker for the presence and amount of coronary atherosclerotic plaque.[44] Both older electron beam CT and MDCT permit accurate detection and quantification of coronary artery cal-

Table 5. Diagnostic accuracy of 64-slice multidetector computed tomography for the assessment of coronary bypass grafts.

Study	Patients	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Meyer et al[32]	138	97	97	93	99
Jabara et al[33]	50	100	100	100	100
Ropers et al[35]	50	100	94	92	100
Malagutti et al[36]	52	99	96	95	99
Pache et al[37]	31	98	89	90	98

NPV – negative predictive value; PPV – positive predictive value.

cium, with a radiation dose of 1-2 mSv.[45,46] The 'Agatston Score', which takes into account the area and the CT density of the calcified lesions, can be easily derived using semi-automated software and is the most commonly used measure of coronary calcification. In some trials, the absence of coronary calcium ruled out the presence of significant CAD with high predictive value, however not every significant atherosclerotic plaque is calcified, and calcification is not a sign of either stability or instability of any individual plaque.[47-48] Coronary calcium score has a strong predictive power for future hard cardiac events in asymptomatic individuals, over and above traditional risk factors. Its widespread use is not recommended, but it can be used to further reclassify individuals at intermediate risk (according to SCORE, PROCAM or Framingham risk assessment) to either a low risk group (zero or very low calcium score) or to a high risk group (high calcium score), which may justify more intensive risk factor modification.[49-55]

Plaque characterization

Unlike invasive coronary angiography, MDCT provides images of both the coronary lumen and the atherosclerotic plaque in the vessel wall. Positive remodeling of the coronary artery wall at the site of the plaque, as well as the eccentricity of the plaque at individual plaque level, can be identified and measured using MDCT.[56] Based on CT density measurements, lipid rich and fibrous plaques can be differentiated from calcified plaques. There is significant overlap in the range of CT values of lipid rich and fibrous plaques, probably reflecting the heterogeneous nature of the plaques.[57] The large variability and low reproducibility of this kind of measurement, as well as the fact that there is only a moderate correlation with intravascular ultrasound, currently prevent accurate plaque characterization and classification of non-calcified plaques by CT.[58] Although small studies have reported a higher fraction of non-calcified plaques and more positive remodeling in patients with acute coronary syndromes in comparison to patients with stable angina, we are still far from being able to identify vulnerable plaques.[59,60]

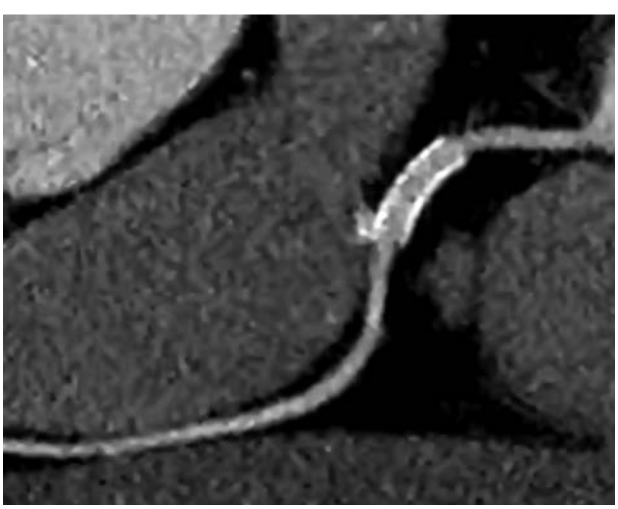

Figure 8. A patent stent in the right coronary artery.

Non-coronary cardiac imaging

Left and right ventricular function

Left and right end-diastolic and end-systolic volumes, stroke volume, ejection fraction and myocardial mass can be calculated from cardiac CT data sets and correlate well with magnetic resonance imaging (MRI) and echocardiography.[61-63] End-systole can be identified from multiphasic and biphasic reconstructions based on the early repolarization phase of the ECG.[62] Echocardiography and MRI remain the methods of choice for the evaluation of left and right ventricular function, since they are accurate and do not require radiation exposure or the use of contrast media.

Myocardial perfusion and viability

Regions of reduced myocardial contrast uptake can be demonstrated early (in the arterial phase of the contrast bolus) in the presence of acute, subacute and chronic myocardial infarction, thus demonstrating perfusion defects.[64,65] Repeat scanning, with a low radiation dose and no further contrast administration 10-15 minutes after the first scan, shows late hyperenhancement in the region of myocardial necrosis, allowing estimation of the extent and transmurality of the necrotic myocardium and, indirectly, the presence of viability. Assessment of myocardial viability with MDCT after acute myocardial infarction has provided prognostic information regarding late remodeling.[66] Late enhancement assessed by CT shows excellent agreement with infarct size assessed by MRI, while early hypoenhancement defects tend to underestimate infarct size.[67] In the setting of an acute myocardial infarction, early hypoenhancement reflects the microvascular obstruction, the so called no-reflow zone (in a way similar to MRI studies because the iodated contrast agents have similar kinetics in infarcted and non-infarcted myocardium as gadolinium).[68] Although MDCT has the advantage of excellent spatial resolution, which allows differentiation of subendocardial ischemia or necrosis, stress echocardiography, SPECT and MRI remain the methods of choice for perfusion and viability studies.

Left atrial-pulmonary vein anatomy

MDCT is becoming widely used in planning electrophysiological procedures and in particular ablation for atrial fibrillation. CT allows accurate imaging of the anatomy of the left atrium and the pulmonary veins (Figure 9) and three-dimensional CT images can be superimposed on the electroanatomical map, improving ablation results and reducing fluoroscopy times.[69] CT delineates surrounding structures (aorta, coronary arteries, esophagus), thus helping to avoid complications during the ablation procedure.

Venous anatomy

MDCT accurately assesses the coronary venous system.[70] Variability in cardiac venous system anatomy (often affected by previous infarcts) may hamper the positioning of a left ventricular lead in cardiac resynchronization therapy. MDCT is the test of choice when anatomical information about the cardiac venous system is needed.

Congenital heart disease

Although radiation exposure is a major drawback, MDCT provides excellent spatial and temporal resolution, rapid image acquisition and advanced three-dimensional post-processing tools; it has become an important diagnostic examination in patients with congenital heart disease (adults and children). MDCT is especially useful in depicting anomalous coronary arteries and in identifying a possible malignant course of a coronary artery between the aorta and the pulmonary trunk (Figures 6, 10).[71]

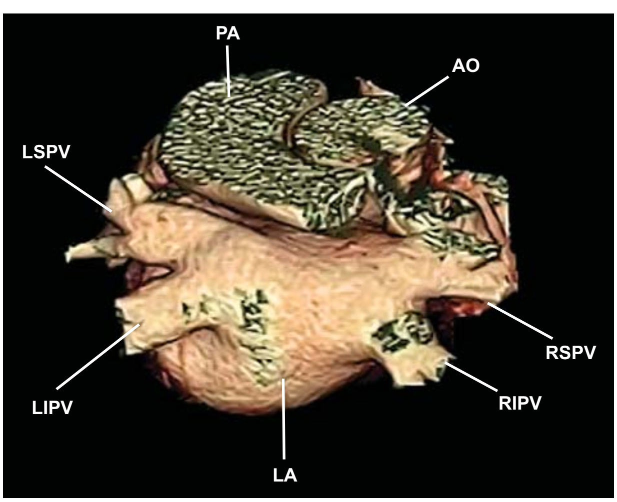

Figure 9. Pulmonary venous anatomy delineation: a volume rendering technique (VRT) image of the left atrium and the four pulmonary veins. AO – aorta; LA – left atrium; LIPV – left inferior pulmonary vein; LSPV – left superior pulmonary vein; PA – pulmonary artery; RIPV – right inferior pulmonary vein; RSPV – right superior pulmonary vein.

Structural lesions

Cardiac masses, thrombi, pericardial diseases, pulmonary artery and aorta pathology can be easily evaluated with MDCT.

Indications

The main advantage of MDCT coronary angiography is the consistently high negative predictive value in all studies. In other words it is an excellent rule-out technique, which should be restricted to symptomatic patients at intermediate pre-test risk of CAD, where a negative CT scan may avoid referral for invasive coronary angiography. MDCT coronary angiography is also useful in patients referred for valve surgery, in patients with new onset dilated cardiomyopathy, in patients with left bundle branch block, and as a technique for ruling out an acute coronary syndrome in the emergency room in the absence of ischemic ECG changes and negative initial biomarkers.[72-75]

Table 6 lists the appropriate clinical indications for the use of cardiac CT, according to an expert consensus document endorsed by several professional societies.[76] Contrast enhanced cardiac CT is contraindi-

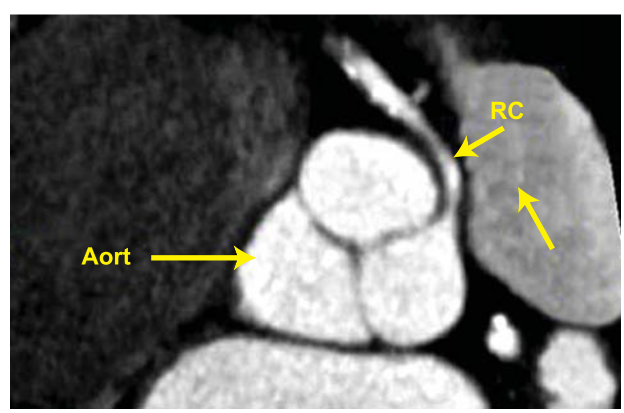

Figure 10. A case of "malignant" course of the right coronary artery (RCA), which arises from the left coronary sinus and courses between the aortic bulb and the pulmonary artery (PA).

cated in patients with renal failure, in those who are unable to lie flat, in those with an allergy to contrast agents, and in pregnant women. Coronary CT angiography is not routinely recommended in patients with arrhythmias, patients with advanced CAD and pronounced coronary calcifications, patients with stents or patients with previous CABG.[77]

Future prospects

MDCT cardiac applications are becoming widely available and extensively adopted. There are still major limitations: radiation dose, arrhythmias, calcifications, metallic implants. CT technology is rapidly developing and will partly resolve these problems.

Dual-source CT

Dual source CT is already available and offers significant improvements in temporal resolution, which is very important in cardiac imaging. Table 7 summarizes the results of dual-source CT coronary angiography studies.[78-84] A prototype 128-detector dual source scanner is already able to acquire a CT coronary angiogram within 1 second, with <2 mSv radiation dose.

Increased number of slices

Scanners with larger arrays and more slices can offer greater volume coverage, thus providing the opportunity of reducing breath-hold time, the number of cardiac cycles needed to cover the heart, and radiation exposure. If the whole heart could be covered in one heart cycle, prospective cardiac gating would become reliable, arrhythmias would no longer be a significant problem and the radiation dose would decrease further. 128-, 256- and 320-slice scanners have been introduced, have been tested and the first preliminary results have been reported.[85]

Table 6. Appropriate indications for cardiac computed tomography (CT).

CT coronary angiography:
- Evaluation of chest pain syndrome:
  - Intermediate pre-test probability of CAD, ECG uninterpretable or unable to exercise
  - Uninterpretable or equivocal stress test (exercise, perfusion, stress echo)
- Evaluation of acute chest pain:
  - Intermediate pre-test probability of CAD, no ECG changes and serial enzymes negative
- Evaluation of suspected coronary anomalies
- Assessment of complex congenital heart disease, including anomalies of the coronary circulation, great vessels and cardiac chambers and valves
- Evaluation of coronary arteries in patients with new onset heart failure to assess etiology
- Noninvasive coronary arterial mapping, including internal mammary artery, before repeat cardiac surgical revascularization

Cardiac CT:
- Assessment of cardiac mass (suspected tumor or thrombus) in patients with technically limited images from MRI or echocardiography
- Evaluation of pericardial conditions (pericardial mass, constrictive pericarditis or complications of cardiac surgery) in patients with technically limited images from MRI or echocardiography
- Evaluation of pulmonary vein anatomy before invasive radiofrequency ablation for atrial fibrillation
- Noninvasive coronary vein mapping prior to placement of biventricular pacemaker

Table 7. Diagnostic performance of dual-source computed tomography for the detection of significant coronary stenosis (luminal diameter >50%) on a per patient basis.

Study	Patients	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Scheffel et al[78]	30	96.4	97.5	85.7	99.4
Weustink et al[79]	100	99	87	96	95
Ropers et al[80]	100	98	84	80	98
Leber et al[81]	90	95	90	74	99
Johnson et al[82]	35	100	89	89	100
Alkadhi et al[83]	150	96.6	86.8	82.6	97.5
Brodoefel et al[84]	100	100	81.5	93.6	100

NPV – negative predictive value; PPV – positive predictive value.

Dual energy

Dual energy is the technique where different areas of interest are scanned with different tube currents. The technique may improve tissue differentiation, which in coronary imaging may theoretically be helpful to overcome the problem of calcification, thus permitting better lumen evaluation. Encouraging initial reports have been published.[86]

Hybrid systems

The combined evaluation of anatomy and perfusion in hybrid systems (PET-CT and SPECT-CT) is emerging and will probably play a significant role in the near future.[42, 43]

Conclusion

Modern MDCT scanners allow noninvasive, accurate visualization of the coronary arteries, permit evaluation of cardiac function, and provide information about extra-cardiac thoracic pathology. MDCT coronary angiography is a noninvasive alternative to invasive coronary angiography that is highly reliable for ruling out obstructive CAD. Current CT technology cannot replace invasive coronary angiography. Expected improvements in spatial and temporal resolution, a further decrease in radiation exposure, development of hybrid systems, the release of more robust clinical guidelines, and proper patient selection will help expand the clinical applications of cardiac CT. Establishment of adequate cardiac CT training programs is necessary and should be encouraged.[87]

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