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Review

Spiral Multislice Computed Tomography Coronary Angiography: A Current Status Report

P. J. De Feyter, M.D., PH.D.,*† W. B. Meijboom, M.D.,*† A. Weustink, M.D.,*† C. Van Mieghem, M.D.,*† N. R. A. Mollet, M.D., PH.D.,*† E. Vourvouri, M.D., PH.D.,† K. Nieman, M.D., PH.D.,* F. Cademartiri, M.D., PH.D.†

*Department of Cardiology, University Hospital Rotterdam; †Department of Radiology, University Hospital Rotterdam, Rotterdam, The Netherlands

Summary

Multislice computed tomography coronary angiography (MSCT-CA) has emerged as a powerful noninvasive diagnostic modality to visualize the coronary arteries and to detect significant coronary stenoses. The latest generation 64-slice computed tomography (CT) scanners is a robust technique which allows high-resolution, isotropic, nearly motion-free coronary imaging. Coronary stenoses are detected with high sensitivity and a normal scan accurately rules out the presence of a coronary stenosis. With the introduction of further novel concepts in CT-technology one may expect that MSCT-CA will become a clinically used diagnostic tool.

Key words: computed tomography, coronary artery disease, coronary angiography

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Introduction

The development of CT has significantly improved noninvasive imaging, initially of nonmoving organs of the body, and recently also of the heart. Electron beam computed tomography (EBCT), a technique especially designed to examine the heart, was introduced in the early 80ties. Nowadays these scanners are largely replaced nowadays by spiral Multislice CT scanners which can detect coronary stenoses and nonobstructive coronary plaques with high diagnostic accuracy.[1,2] This report highlights the current status of multislice computed tomography coronary angiography (MSCT-CA), discusses its limitations and speculates about the role and future of MSCT-CA in clinical practice.

High-Quality, Motion Free CT Images: Spatial and Temporal Resolution

Coronary imaging requires the highest technical demands of any noninvasive diagnostic modality because of the small size of the coronary arteries, the continuous motion during cardiac contraction and the inevitable respiratory motion.

The spatial resolution should be as high as possible and ideally isotropic voxel imaging should be achieved. Isotropic imaging means that a voxel has the same size in all dimensions and is mandatory to reconstruct high-quality images in all planes.

The spatial resolution of current CT-scanners is 0.4 mm^3.

High temporal resolution is mandatory to obtain motion-free image quality. The temporal resolution is defined as the required time for data acquisition per slice, and for cardiac spiral CT it refers to the duration of the reconstruction window during the end-diastolic phase of each heart cycle (Fig. 1). The temporal resolution depends on the X-ray tube rotation-time and is equal to half of the X-ray tube rotation-time. Current 64-slice spiral CT-scanners have a temporal resolution of 165 to 200 ms.

Address for reprints:
P. J. De Feyter, M.D., PH.D.
University Hospital Rotterdam
Thoraxcenter Hs 207
P.O. Box 2040
3000 CA Rotterdam, The Netherlands
e-mail: p.j.defeyter@erasmusmc.nl

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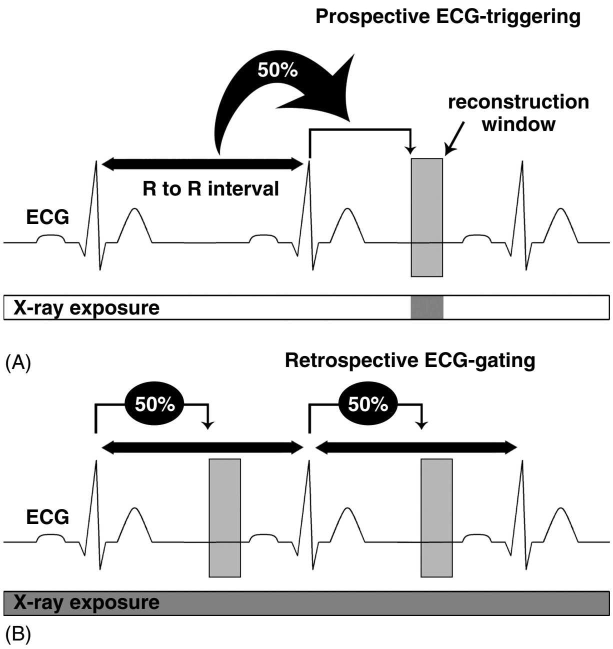


FIG. 1 ECG-synchronized image reconstruction. (A) Sequential scan protocols use prospective ECG-triggering to synchronize the data acquisition to the motion of the heart. On the basis of the measured duration of the previous heart cycles, the scan of one or more slices is initiated at a prespecified moment after the R-wave, for instance at 50% of the previous R-to-R intervals. (B) Spiral CT scanners acquire data continuously and record the patients ECG during the scan. Isocardiophasic images are reconstructed using retrospective ECG-gating. The reconstruction window can be positioned anywhere within the R-to-R interval, and images can be created during any phase, for instance at 50%. The duration of the reconstruction window determines the temporal resolution.

MSCT Acquisition Modes and ECG-Synchronization

The CT-data necessary for the reconstruction of the CT-imaging are acquired either in sequential mode or spiral mode. In the sequential mode the scanner acquires the data of one slice, after which the table (and thus the patient) is advanced to the next plane position to acquire the next data of an adjacent slice (slice-by-slice acquisition or stop-and-shoot principle). In the spiral mode, the CT-data are acquired continuously while the table (and thus the patient) moves at a constant speed.

The CT-data used for image reconstruction are preferentially obtained in the relatively motion-free mid-to-end diastolic phase of the cardiac cycle. This requires simultaneous recording of the ECG signal during the CT-scan. Prospective ECG-triggering is used in the sequential model to prospectively acquire the CT-data in a certain predefined cardiac phase (in general the mid-to-end diastolic phase) (Fig. 1). A retrospectively ECG-gated technique is used in the spiral mode which allows to select retrospective reconstruction of CT-data in any, but preferentially the mid-to-end diastolic phase of the cardiac cycle (Fig. 1). Using this technique, data is acquired throughout the entire cardiac cycle, but only data of a small part of the cardiac cycle is used for image reconstruction after the scan has been performed. The sequential mode with prospective ECG-triggering is used for CT calcium scoring, and the spiral mode with retrospective ECG-gating is used for contrast-enhanced CT coronary angiography.

Scan Time

On average the cranio-caudal size of the heart measures 10 to 12 cm, but can be larger with ischemic heart disease. MSCT should cover the entire heart. The scan time is inversely related to the X-ray tube rotation speed and number of detector-rows (or reconstructed slices). Current CT-scanners have an X-ray tube rotation time of 330 to 400 ms and number of detectors rows (slices) of 64, which results in a scan time of less than 10 s.

Tissue Contrast and Image Quality

The differences in X-ray attenuation between nonenhanced coronary blood, the vessel wall and epicardial fat

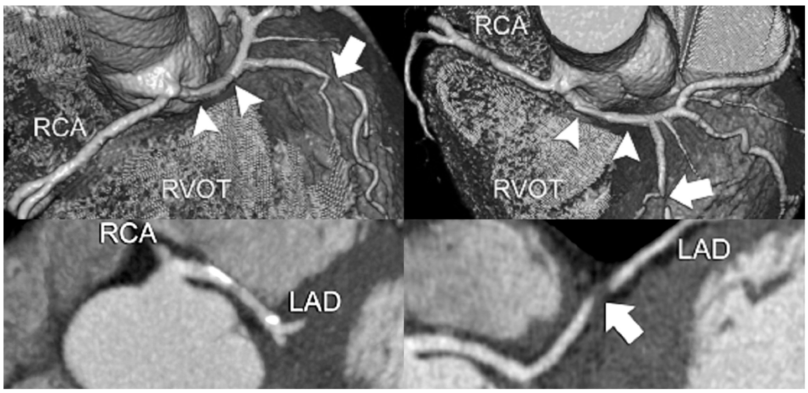
TABLE 1 Diagnostic performance of 64-MSCT for detection of significant coronary stenosis (luminal diameter >50%)

	Segmental analysis						
Author	Year	NP	Excl. Segm. %	Sensitivity %	Specificity %	PPV %	NPV %
Leschka	2005	67	0	94	95	88	98
Leber	2005	55	0	76	97	75	97
Raff	2005	70	12	86	95	66	99
Mollet	2005	51	0	99	95	76	99
Ropers	2006	81	4	93	97	56	100
Schuijf	2006	60	1.4	85	98	82	96
Ong	2006	134	9.7	82	96	83	96
Total (weighted)		518	4.7	89	96	78	98.5

TABLE 2 Diagnostic performance of 64-MSCT for detection of significant coronary stenosis (luminal diameter > 50%)

			Patient-based analysis			
Author	Year	NP	Sensitivity %	Specificity %	PPV %	NPV %
Leschka	2005	67	100	100	100	100
Leber	2005	45	88	85	88	85
Raff	2005	70	95	90	93	93
Mollet	2005	51	100	92	97	100
Ropers	2006	81	96	91	83	98
Schuijf	2006	60	94	97	97	93
Total (weighted)		374	96	92	94	95

* 4 patients were excluded.



(A) (B) (C) (D)

FIG. 2 The left main and right coronary artery (RCA) arise from the right aortic sinus A–D. The anomalous left main coronary artery runs between the aorta and pulmonary trunk (arrowheads). Note also the severe stenosis (arrow) of the left anterior descending artery (LAD). RVOT: right ventricular outflow tract.

are small and therefore hardly visible by MSCT imaging. An intravenous bolus injection of 80 to 100 mL of high iodinated X-ray contrast is administered to allow differentiation of the contrast-enhanced coronary lumen from the coronary wall and coronary atherosclerotic plaques, which then permits detection of coronary lumen obstructions and nonobstructive coronary plaques.[3]

Heart-Rate Related Image Quality

CT-data used for reconstruction of coronary images are usually obtained from the relative motion-free mid-to-end diastolic phase of the cardiac cycle to reduce motion-artifacts. The duration of the motion-sparse diastolic phase is directly related to the heart rate, since faster heart rates have a shorter diastolic period. Therefore heart rates more than 70 b.p.m. are reduced to prolong the relative motion-free mid diastolic phase, by administration of an oral or intravenous *β*-beta-blocker prior to the CT-investigation. It has been shown that the use of β-blockers results in better quality of the CT-coronary images.[3]

Radiation Exposure and Image Quality

The radiation exposure (i.e. the effective dose) of diagnostic invasive coronary angiography is approximately 6.0 mSv. The radiation exposure during Multislice CT scanning using a gated retrospective reconstruction protocol is considerably higher. The radiation exposure of the 64-slice CT scanner using a continuous scan mode is estimated as an effective dose of 15.2 mSv for males and 21.4 mSv for females.[4] Reduction of the X-ray radiation exposure can be achieved by the use of an ECG controlled X-ray tube current modulation. This feature reduces the tube current during the systolic phase and gives a full X-ray tube current only during the diastolic phase of the cardiac cycles, when the coronary image is reconstructed. This feature can reduce the effective dose by approximately 40% in slow heart rates.

64-Slice Spiral CT Scanner

The 64-slice CT-scanner boosted a major improvement in image quality and robustness of CT-coronary angiography. The assessability of the coronary tree was

FIG. 3 Curved multiplanar reconstructed images demonstrate the presence of a significant lesion in the LAD (A, C, D). The corresponding diagnostic invasive coronary angiogram (B) confirms the presence of a significant coronary stenosis in the proximal LAD. The bright dots represents coronary calcium deposits.

significantly increased and now included almost all major coronary segments and the larger side branches. The 64-slice MS-CT scanner has a spatial resolution of $0.4 \times 0.4 \times 0.4$ and a temporal resolution of 330–400 ms (tube rotation speed) which has reduced the total scan time and hence the single breath hold time to 6–12 s.

The diagnostic performance of the 64-slice spiral CT scanner to detect a significant stenosis is presented in Table 1.[5–11] The analysis was done per coronary segment according to the 17 coronary segment model of the AHA. The number of inevaluable coronary segments is reduced to an average of 4.7% while three studies did not exclude any coronary segment from analysis. The sensitivity was 89% (range 76–99%), specificity 96% (range 95–97%), the predictive value 78% (range 56–88%) and negative predictive value 98.5% (range 96–100%). The patient-based analysis (any disease per patient) is presented in Table 2.

Current Role of MSCT-CA in Clinical Practice

The presence of coronary anomalies can be adequately assessed by MSCT-CA (Fig. 2).

It has been shown that the diagnostic performance of 64 slice CT-scanners to detect coronary stenoses is high in patients who have a high prevalence of coronary artery disease (Fig. 3). In these patients the negative predictive value of 64 CT-scanners, as was shown in all published reports, is very high allowing to exclude the presence of significant coronary artery disease with a very high accuracy. However, there is no or only little information about the diagnostic performance of CT coronary angiography in patients with a low to intermediate likelihood of coronary artery disease.

In addition the role of MSCT-CA in patients with unstable angina or non-ST-segment elevation myocardial infarction is beginning to evolve (Fig. 4).

Spiral CT coronary angiographic techniques are constantly improving and should result in more reliable coronary imaging, which will further affect (evolving) indications.

Spiral CT for stent evaluation

Coronary stents are difficult to assess with spiral CT stent related high density artifacts. Owing to the "blooming" artifact the apparent size of the stent struts is enlarged thereby obscuring the visualization of the in-stent lumen. Sixteen spiral CT is reliable to detect stent occlusion but nonocclusive in-stent restenosis or the more subtle in-stent neo-intimal hyperplasia remains largely unidentified. Improved spatial resolution of 64-slice scanners should allow more accurate assessment of in-stent restenosis, but published reports in humans are still lacking.

MSCT: post-CABG evaluation

Since the motion of coronary bypasses is limited and the size is relatively large it is relatively easy for MSCT to visualize these grafts. The sensitivity and specificity for graft patency of 16-slice spiral CT was 98% for both vein and arterial grafts with a PPV of 92% and NPV of 99% after exclusion of 6% nonevaluable segments Table 3.[12–17] Stenosis assessment in grafts was less accurate and the sensitivity, specificity, PPV and NPV was 91%, 98%, 83% and 99% respectively. Initial experience with the 64 spiral CT-scanner showed somewhat better results. The sensitivity, specificity, positive and negative predictive value was 96%, 100%, 100%, 98% respectively in a study of 64 patients.[18]

Limitations of Spiral CT Coronary Angiography

Persistent irregular heart rhythm such as atrial fibrillation and frequent extra systoles precludes the use of MSCT-CA. However, an occasional extra systole can be corrected by postprocessing ECG-editing.

High-density material, such as calcified plaques or stents cause several image artifacts (e.g. blooming, partial voluming and beam hardening), which may hamper accurate assessment of the integrity of the coronary lumen. In particular, severe coronary calcifications do not allow inspection of the underlying coronary lumen, and cause misinterpretation. Moreover, coronary calcifications adjacent to a lumenal obstruction may overestimate the severity of the obstruction.

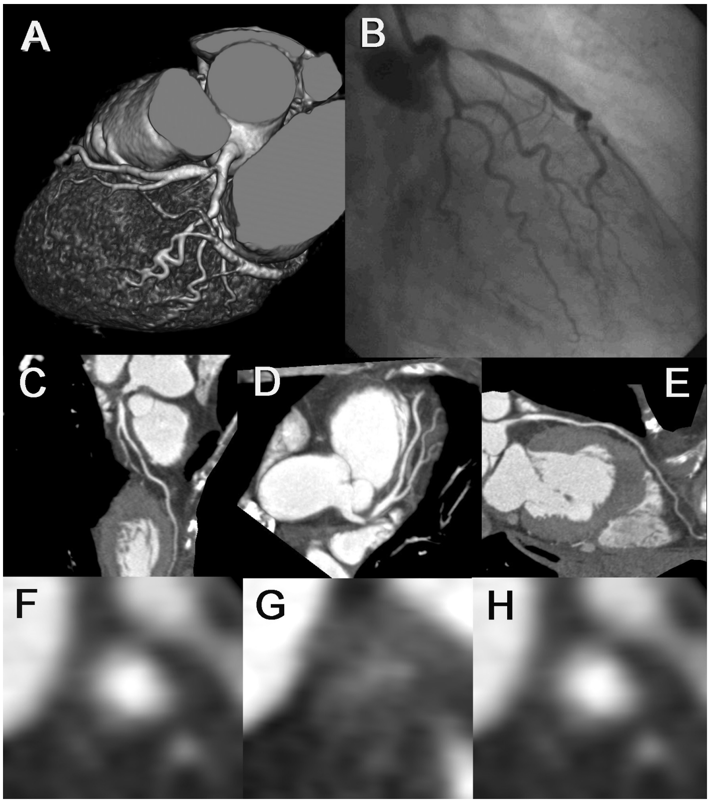


FIG. 4 CT coronary angiogram and corresponding conventional angiogram of the left coronary artery in a patient presenting with unstable angina. Note that the volume-rendered images (A) provide an excellent anatomic overview of the coronary arteries but should not be used to score the presence and degree of coronary stenoses. Two detailed curved multiplanar reconstructed (cMPR) CT image (C, E) and a maximum-intensity projection reveal the presence of a significant stenosis located at the proximal LAD, which was confirmed on the conventional angiogram (B). Cross-sectional CT images show a large noncalcific plaque (G) and a normal coronary lumen of the left main (F) en distal LAD (H).

TABLE 3 16 slice spiral CT for assessment of vessel occlusion in bypass grafts

Author	NP	Excluded segm.	Sensitivity %	Specificity %	PPV %	NPV %
Martuscelli	96	12	100	100	100	100
Chiurlia	52	1	100	100	100	100
Schlosser	48	4	95	95	81	99
Yamamoto	42	4	93	100	33	100
Anders	32	0	100	98	96	100
Salm	25	8	100	93	100	99
Total (weighted)	295	6	98	98	92	99

Future of MSCT Coronary Angiography

The quality of current MSCT coronary imaging is still hampered by the limited temporal and spatial resolution. Novel technical advances have been developed to address these issues by either increasing the number of detector rows (slices) or by increasing the X-ray tube rotational speed. A 256 detector CT-scanner has been introduced which allows assessment of LV-function and the proximal coronary arteries but currently the performance is severely limited by the long-scan time and poor temporal resolution.[19]

A significant step forward has been the very recent introduction of the Dual-source 64 slice CT-scanner which has decreased the temporal resolution (to 83 ms) by use of two X-ray sources and two detectors, while the shorter scan time, in combination with a shorter ECG-gated maximal X-ray tube output should significantly lower the radiation dose.[20,21] The improved temporal resolution allows "motion-free" imaging also at higher heart rates thus obviating the need for preinvestigational *ß*-blockade. Clinical evaluation of this new CT-technology in a wide spectrum of patients should reveal whether this degree of expected image-improvement will suffice for clinical decision making in an individual presenting with chest pain.

Further novel technical approaches requiring many years will be needed to resolve the problems associated with coronary calcification (subtraction techniques using dual-X-ray sources?) and arrhythmia's (volumetric imaging during one heart beat).

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