Case report

Computed tomography coronary angiography with a 16-row multislice scanner: early experience and technical considerations

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Abstract. The visualization of coronary arteries has become possible only after the introduction of multislice CT scanners (MSCT), which allow a gantry rotation time of 500/ms, a number of 4 detector array, and an in-plane spatial resolution of 1 mm. Such spatial and temporal resolution has been recently improved with a new generation of MSCT scanners with 16 detector rows and a gantry rotation time of 420/ms. We report a preliminary experience with this new generation of scanners in a patient with coronary artery stent. Technical parameters are described with particular focus on the comparison with the past generation of 4-row MSCT scanners.

Key words: Coronary angiography, 16-row MSCT, CT angiography, coronary artery stent

Introduction

Single detector spiral computed tomography (CT) with retrospective electro-cardio-graphic (ECG) gating does not allow a continuous scan of heart and coronary arteries in a reasonably short time, compatible with the apnea of the average patient (1, 2).

The visualization of coronary arteries has become possible only after the introduction of multislice CT scanners (MSCT), which allow a gantry rotation time of 500/ms, a number of detector rows as high as 4, and an in-plane spatial resolution in the range of 1 mm. With this technology it is now possible to scan the region of the heart and coronary arteries in a single breath-hold (2).

The retrospective ECG gating is recognized as the standard for coronary imaging with MSCT (3-5). With its very high spatial resolution in the z-axis, yet MSCT angiography at high heart rates is limited by a low temporal resolution (125-250/ms depending on the reconstruction algorithm and the heart rate of the patient), especially when compared with other non-invasive modalities for the visualization of coronary arteries, such as electron beam CT (EBT) and magnetic resonance (MR) (4, 6-10).

Nevertheless, these latter techniques suffer from several limitations. The EBT, with scan time in the range of 50-100/ms (allowing a prospective triggering of the scan with consequent reduction of radiation dose), suffers from low in-plane spatial resolution (matrix 512x512; 7-8 linepairs/cm; minimum pixel size 0.83 mm in the scan plane) and in the longitudinal plane (minimum slice thickness 1.5 mm that increases to 3 mm with temporal resolution of 50/ms) (9-12). The MR, also with very fast acquisition time for a single slice (<50/ms that allows as for EBT a prospective triggering), suffers from a compromise between spatial and temporal resolution (matrix 126x256). Instead, MSCT can rely on a very high in-plane spatial resolution (matrix 512x512; 14.7 linepairs/cm; minimum pixel size

0.25 in the scan plane) and in the longitudinal plane (effective slice thickness 1.00-1.25 mm) (13).

Because of these features coronary arteries can be visualized with a 4-row MSCT scanner in the telediastolic phase with retrospective ECG gated reconstruction, when coronary artery motion is minimized (2). Some authors reported encouraging results in evaluation of coronary artery disease with MSCT (4, 14).

Recently a new generation of 16-row MSCT scanners has been introduced bringing faster rotation time (420/ms), thinner slices (0.75 mm), and 16 arrays of detectors. Good results have been reported in the assessment of coronary arteries with this technology (15, 16).

In this paper we report our preliminary experience with a prototype of a 16-row MSCT scanner in the evaluation of stent patency. Moreover, technical features of the new generation of 16-row MSCT scanners will be briefly discussed.

Case Report

The patient (H.S., 54-year-old male) was enrolled for the scan because of his mild non-specific symptoms. In 1999 the patient underwent percutaneous coronary intervention with stent implantation (2.5 mm diameter and 13 mm length) in the proximal left anterior descending (LAD), and from then on he was asymptomatic. The patient gave written informed consent for the procedure.

Scan parameter for 16-row MSCT

The scan was performed in November 2001 at the Research and Development Center of Siemens Medical Solutions located in Forchheim (Germany) with a prototype of the new generation of 16-row MSCT scanners.

The heart rate (HR) prior to the scan was 80 beat per minute (bpm), and was reduced to 65 bpm by means of oral administration of 100 mg of metoprolol-tartrate 45 minutes prior to the scan.

For vascular enhancement an iodinated non-ionic contrast material (CM) with high concentration of iodine (Iomeprol, Iomeron 400 mgI/ml, Bracco Imaging, Italy) was administered through an antecubital vein. To administer the CM a double-head power injector was used (Injektron CT2, Medtron, Germany). Before angiographic acquisition a test bolus with 20 ml of CM was followed by a saline chaser of 40 ml, both injected at 4.0ml/s. The monitoring scan was empirically positioned (it was not possible to perform a topogram/scout view) at the level of the ascending aorta and it run with a rate of one scan every 2s and a starting delay of 12s. The maximum attenuation was detected at 24s and a delay of 28s was chosen.

To obtain a constant attenuation, a biphasic injection protocol was applied: 50 ml at 4 ml/s and then 70 ml at 2.5 ml/s (overall volume: 120 ml of CM), followed by 50 ml of saline chaser at 2.5 ml/s.

The main scan parameters were: number of detectors/collimation 12/0.75 mm, feed/rotation 2.78 mm (pitch: 0.31), rotation time 420/ms, kV 120, mAs 400, and cranio-caudal direction.

Images were reconstructed using a retrospective ECG gating technique based on R wave. The reconstruction window was set in the diastolic phase of the cardiac cycle at 60% of the R-R interval. The effective slice thickness was 1.0mm with a reconstruction index of 0.6 mm. Using a field of view of 150 mm, the size of the voxel was 0.5 mm x 0.5 mm x 0.6 mm. The longitudinal scan range was 140 mm and the total scan time was 21s.

The reconstruction of the datasets required almost two hours because they needed to be done off-line. The reconstructed images were sent to a dedicated workstation for three-dimensional post-processing (Leonardo – Siemens, Germany). Here panoramic maximum intensity projection (MIP) images were performed to locate the stent (Fig. 1). Selective reconstructions of smaller volumes enclosing the stent were performed with dedicated filters in order to increase the contrast among the stent, the lumen of the vessel and the surrounding structures (Fig. 2A, 2B, and 2C). Moreover, three-dimensional reconstructions with volume rendering were performed (Fig. 2D).

Discussion

From the technical and clinical point of view the scan was successful. Calcifications were observed

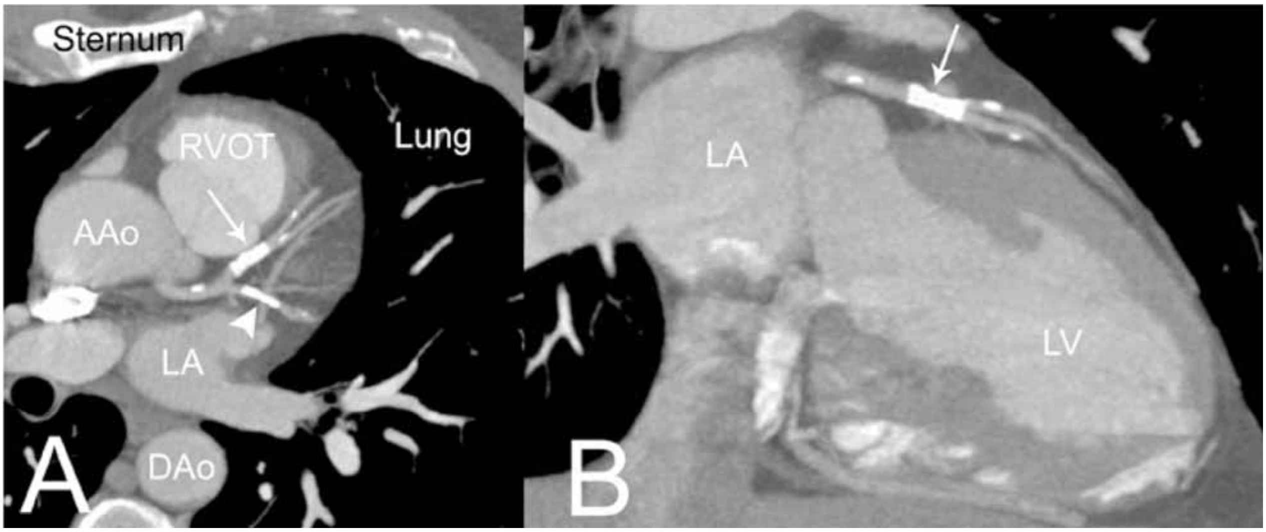

Figure 1. Maximum Intensity Projection reconstructions (MIPs). The visualization of the dataset by means of MIP images allows easily to recognize and to follow vascular structures and their macroscopic alterations. In the para-axial plane (A) it is shown the stent on the LAD (arrow) before the first diagonal branch, while in the para-sagittal plane (B) the relationship between the stent and the underlying left ventricle myocardium is showed. A longitudinal calcified plaque is clearly displayed in the proximal tract of the circumflex (arrowhead).
Abbreviations: AAo= Ascending aorta; DAo= Descending aorta; LA= left atrium; LV= left ventricle; RVOT= right ventricle outflow tract.

along the left circumflex, especially in the mid tract. Any significant stenosis was detected.

The presence of the stent was detected (Fig. 1). In spite of the small diameter, the MSCT appearance was satisfactory, particularly in sagittal reconstructions, if compared with our previous experience with 4-row MSCT scanners.

The region of the stent was reconstructed also with dedicated algorithms and filters making it sharper (Fig. 2). The accuracy of attenuation measurements inside the stent to ensure patency is still under validation but it seems to suffer from beam-hardening and blooming artifacts.

Reconstructed images and multiplanar images (Fig. 2) demonstrated the absence of significant stenosis or occlusion of the stent. The clinical findings in the patient were in agreement with MSCT findings.

Some issues were observed in this particular experimental context.

The *first* one is related to the well-known beam-hardening effect, which determines a shadow of attenuation along the path of the X-ray beam. In simple words, the high density of the material of the stent determines a reduction in the attenuation in its inner region. In this case the reduction in the attenuation value was 61HU±33. This pitfall depends on the diameter and the material of the stent. The evaluation of stent patency was nevertheless possible.

The *second* is related to the vascular attenuation obtained in the main coronary branches equal to 190-200 HU with the presence of a slight venous enhancement. This value should be considered sub-optimal based on our previous experience with 4-row MSCT scanners. In fact, with the previous 4-row MSCT scanner we could obtain values of attenuation around 300 HU. The main explanation for this observation is that, for safety reasons, we added more seconds than needed to the actual delay calculated on the basis of test bolus technique. It is reasonable to expect from protocol optimization, for instance with real-time bolus tracking techniques, that this problem will be solved in creasing the efficacy of contrast material administration.

In order to better evaluate the technical improvements related to the new scanner we describe the protocol used in our Institution with the 4-row MSCT scanner (Somatom Plus 4 Volume Zoom, Siemens, Germany).

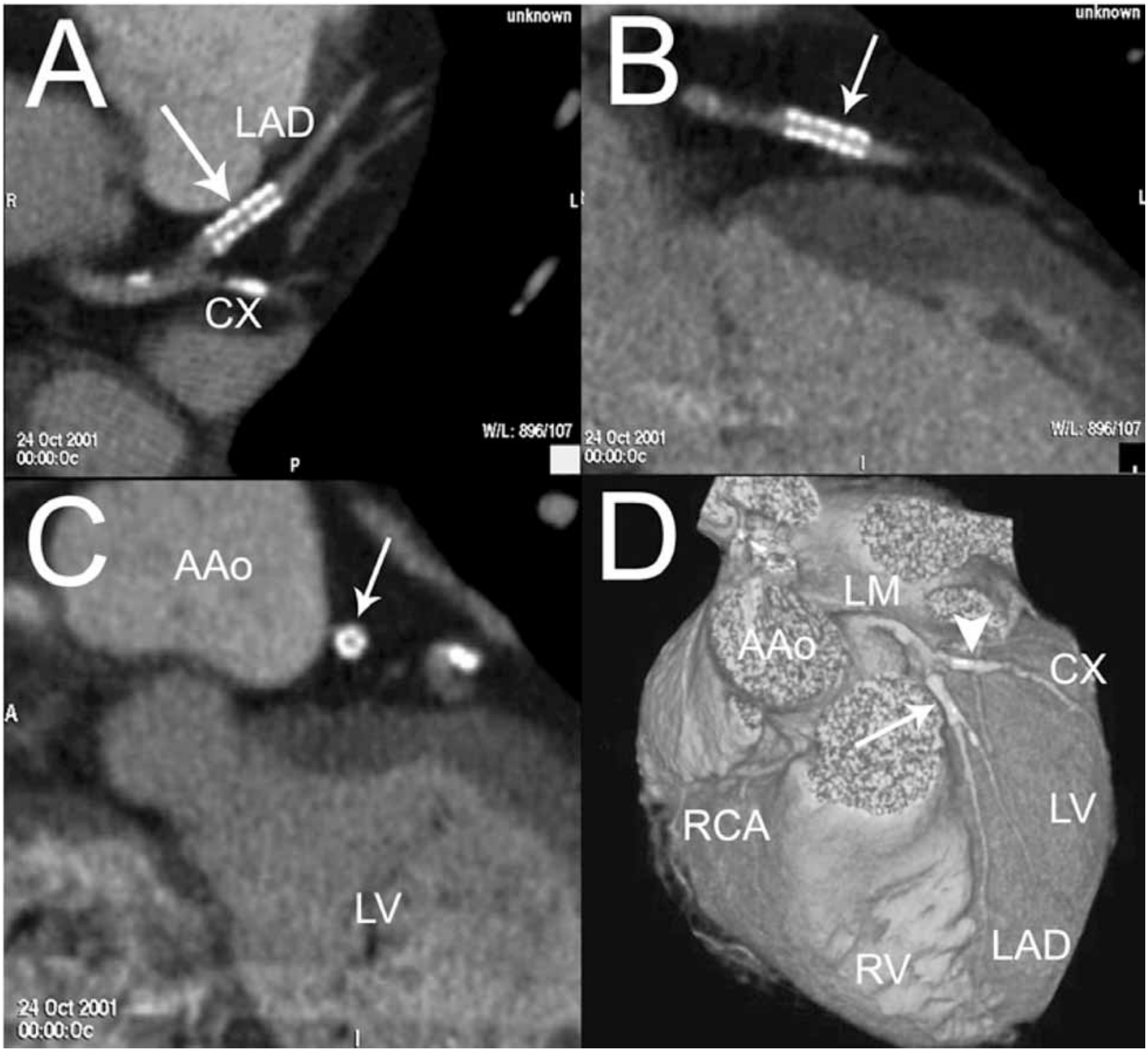

Figure 2. Multiplanar images and three-dimensional reconstructions with volume rendering. The stent (arrow) is visualized by means of three planes passing through the main axis: the axial plane (A), the para-sagittal plane (B), the coronal plane (C). The patency is better displayed in the axial and para-sagittal planes (A and B), while the coronal plane (C) shows sub-optimal image quality. The three-dimensional volume rendering (D) improves the anatomical perception of the vessels, the stent (arrow), and the linear calcification in the proximal circumflex (arrowhead).
Abbreviations: AAo= Ascending aorta; CX= circumflex; LAD= left anterior descending; LM= Left main; LV= left ventricle; RCA= right coronary artery; RV= right ventricle.

The optimal heart rate was approximately 60 bpm. When the patient showed a heart rate above 70 bpm at presentation, 100 mg of metoprolol-tartrate were administered orally. In ideal conditions, during the main scan, the heart rate should drop below 65 bpm. In order to calculate the delay for the main scan a test bolus technique was used with 15-20 ml of CM and 20ml of saline chaser administered at 4 ml/s, through an antecubital vein. The monitoring scans were performed at the level of ascending aorta and started 12s after the beginning of test bolus administration with a rate of one image every 2s. The scan showing the highest attenuation in the ascending aorta was chosen as delay for the main angiographic scan .

The scan parameters were: number of detectors/collimation 4/1 mm, feed/rotation 1.5 mm, rotation time 420/ms, kV 120, mA 300, scan direction cranio-caudal. The scan range was 120mm and the scan time was 35-40s.

During the main scan the CM was administered with a biphasic protocol to improve the length of the plateau of attenuation: 50 ml at 4 ml/s and 70-100 at 2.5 ml/s (for an overall CM volume of 120-150 ml), then 40 ml of saline chaser at 2.5 ml/s.

Reconstruction parameters were: effective slice width 1.25 mm, reconstruction index 0.8 mm. The voxel size was therefore 0.35 mm x 0.35 mm x 0.8 mm. The image reconstruction speed was 1.5 image/s. The retrospective ECG-gating was generally performed at 50-60-70% (or 450-400-350/ms before the next R wave) of the R-R interval. The field of view (FOV) for the reconstruction was 180mm.

From the technical standpoint, the improvements due to the new generation of MSCT scanners are affecting three main parameters: 1) collimation, 2) number of detectors and 3) gantry rotation time.

The *first* parameter (e.g. collimation), drops from 1mm to 0.75 mm causing a reduction of the minimum effective slice width from 1.25 mm to 1 mm (-20%). This improvement affects longitudinal spatial resolution and allows to obtain a more isotropic voxel (e.g. a voxel where the three sides are almost the same in length and is approximately like a cube).

The *second* parameter (e.g. number of detectors), increases from 4 to 12 detectors in the case of our prototype. In the final version of the scanner it will be possible to scan with retrospective ECG gating using all 16 rows of detectors. Nevertheless this determines a three-fold increase in scan speed with all the other parameters unchanged. The scanner prototype used for this preliminary experience was equipped with 16 rows of detectors but able to scan the heart with 12 detector rows. This allowed to neglect the application of cone-beam correction algorithms. The reconstruction algorithm applied in this case was the same used for the 4-row scanner. This algorithm is called AAI (Adaptive Axial Interpolation) and it keeps constant pitch-independent slice width, and uses the full applied dose to the patient (17). The resulting assumption is that parallel beams, neglecting the angle deformation, constitute the X-ray cone-beam.

When more than 4 detector rows are present the cone-beam correction needs to be applied because of the image deformation (17). In our case it was possible to neglect the cone-beam artifact and obtain high-quality images because in cardiac imaging the FOV is small and located at the iso-center of the scanner where the deformation of the cone-beam is negligible. In this region in fact the beams are more parallel and the deformation is minimized compared with peripheral area of the FOV (17).

The *third* parameter (e.g. gantry rotation time), drops from 500/ms to 420/ms (-16%). This determines an improvement not only of the scan time but, more significantly, of temporal resolution, which is the key for motion-free cardiac imaging. In simple words, is like having a faster exposure time in your camera. It will be easier to photograph moving objects without image blurring. The effective temporal resolution, in fact, can reach 210/ms with the currently available algorithm, and can drop down to 105/ms depending on the heart rate applying a bi-segmental reconstruction. This last algorithm can create an image merging the information from two adjacent cardiac cycles. The gantry rotation speed is limited by two main factors. The first is the centrifugal force generated inside the system X-ray tube-slip ring-detector array (due to the weight and the radius of the rotating system) which increases quadratically; for instance, from 500/ms to 420/ms rotation time, the centrifugal force shifts from 9 g to 13 g. The second factor is the amount of information that can be transferred per second from the moving equipment (the system X-ray tube-detectors) to the fixed structure of the gantry through the slip-ring. Further improvements will lead to new lighter and more powerful X-ray tubes, able to carry out high centrifugal forces, and a faster data transfer from the rotating system.

From the clinical standpoint these observations are translated as follows. The time needed to scan the heart drops from 40s to 21s, even with an increase of the scan range from 120 mm to 140 mm, and a collimation reduction from 1mm to 0.75 mm (effective slice width 1.25 mm and 1 mm, respectively). This determines a better spatial resolution in the scan plane and in the longitudinal axes, with a concomitant reduction of the breath-hold problem in the majority of the cases.

In conclusion, this preliminary clinical experience shows that this new generation of MSCT scanners brings significant improvements in scan speed, spatial and temporal resolution. A small size coronary stent has been easily and clearly visualized. On the basis of these observations it is reasonable to expect an improvement in clinical performance that will widen the range of application for non-invasive coronary angiography with MSCT.

References

1. Kachelriess M, Kalender WA. Electrocardiogram-correlated image reconstruction from subsecond spiral computed tomography scans of the heart. *Med Phys* 1998; 25: 2417-31.
2. Ohnesorge B, Flohr T, Becker C, et al. Cardiac imaging by means of electrocardiographically gated multisection spiral CT: initial experience. *Radiology* 2000; 217: 564-71.
3. Nieman K, van Ooijen P, Rensing B, Oudkerk M, de Feyter PJ. Four-dimensional cardiac imaging with multislice computed tomography. *Circulation* 2001; 103: E62-2.
4. Achenbach S, Ulzheimer S, Baum U, et al. Noninvasive coronary angiography by retrospectively ECG-gated multislice spiral CT. *Circulation* 2000; 102: 2823-8.
5. Becker CR, Ohnesorge BM, Schoepf UJ, Reiser MF. Current development of cardiac imaging with multidetector-row CT. *Eur J Radiol* 2000; 36: 97-103.
6. van Geuns RJ, Wielopolski PA, de Bruin HG, et al. MR coronary angiography with breath-hold targeted volumes: preliminary clinical results. *Radiology* 2000; 217: 270-7.
7. Kessler W, Laub G, Achenbach S, et al. Coronary arteries: MR angiography with fast contrast-enhanced three-dimensional breath-hold imaging-initial experience. *Radiology* 1999; 210: 566-72.
8. Achenbach S, Moshage W, Bachmann K. Detection of high-grade restenosis after PTCA using contrast-enhanced electron beam CT. *Circulation* 1997; 96: 2785-8.
9. Achenbach S, Moshage W, Ropers D, Nossen J, Bachmann K. Noninvasive, three-dimensional visualization of coronary artery bypass grafts by electron beam tomography. *Am J Cardiol* 1997; 79: 856-61.
10. Achenbach S, Moshage W, Ropers D, Nossen J, Daniel WG. Value of electron-beam computed tomography for the noninvasive detection of high-grade coronary-artery stenoses and occlusions. *N Engl J Med* 1998; 339: 1964-71.
11. Achenbach S, Ropers D, Regenfus M, et al. Contrast enhanced electron beam computed tomography to analyse the coronary arteries in patients after acute myocardial infarction. *Heart* 2000; 84: 489-93.
12. Rensing BJ, Bongaerts AH, van Geuns RJ, et al. In vivo assessment of three dimensional coronary anatomy using electron beam computed tomography after intravenous contrast administration. *Heart* 1999; 82: 523-5.
13. Hu H, He HD, Foley WD, Fox SH. Four multidetector-row helical CT: image quality and volume coverage speed. *Radiology* 2000; 215: 55-62.
14. Nieman K, Oudkerk M, Rensing BJ, et al. Coronary angiography with multi-slice computed tomography. *The Lancet* 2001; 357: 599-603.
15. Ropers D, Baum U, Pohle K, et al. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. *Circulation* 2003; 107: 664-6.
16. Nieman K, Cademartiri F, Lemos PA, et al. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. *Circulation* 2002; 106: 2051-4.
17. Schaller S, Flohr T, Klingenbeck K, et al. Spiral interpolation algorithm for multislice spiral CT-part I: theory. *IEEE Trans Med Imaging* 2000; 19: 822-34.

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