Computed Tomographic Assessment of Coronary Artery Disease

State-of-the-Art Imaging Techniques

Thomas G. Flohr, PhD[a,b,*], Carlo Nicola De Cecco, MD[c,d], Bernhard Schmidt, PhD[a], Rui Wang, MD[d], U. Joseph Schoepf, MD[d], Felix G. Meinel, MD[d,e]

KEYWORDS

- Coronary CT angiography • Cardiac computed tomography • ECG-gated scanning
- ECG-triggered scanning • Iterative reconstruction • First-pass enhancement scanning
- Dual-energy computed tomography • Cardiac perfusion computed tomography

KEY POINTS

- Excellent temporal resolution and spatial resolution are key to clinically robust computed tomography (CT) coronary angiography.
- Electrocardiography-triggered sequential scanning is radiation dose efficient and should be the method of choice for most cardiac CT examinations. Depending on the patient's size and shape, scanning at low x-ray tube voltage (70 - 100 kV) may significantly reduce the radiation dose.
- Coverage of the heart in one heartbeat is possible with large-area detectors or high-pitch spiral scanning.
- Assessment of both coronary artery morphology and the status of myocardial perfusion with CT is a coveted goal. New techniques such as dual-energy cardiac CT or dynamic myocardial perfusion CT show promising results.

INTRODUCTION

Imaging of the heart with computed tomography (CT) is technically demanding. On the one hand, high temporal resolution is required: the shorter the acquisition time of a CT image, the better will the moving anatomy of the heart and the coronary arteries be visualized. On the other hand, spatial resolution has to be excellent, because the coronary arteries have diameters of only a few millimeters, and not only their lumen but also plaque and stenosis need to be evaluated. To image the heart in a phase-consistent way, for example, in the diastolic rest phase, data acquisition has to be synchronized with the patient's electrocardiogram (ECG). Finally, the radiation exposure to the patient should be as low as reasonably achievable.

Multidetector-row CT (MDCT) has been used for cardiac imaging since the advent of 4-slice CT scanners in 1999.[1–6] Available since 2004, 64-slice CT systems are currently considered prerequisite for

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[a] Siemens Healthcare, Computed Tomography, Siemensstr. 1, Forchheim, Germany; [b] Institute of Diagnostic Radiology, Eberhard-Karls-University, Tübingen, Germany; [c] Department of Radiological Sciences, Oncology and Pathology, University of Rome "Sapienza", Latina, Italy; [d] Department of Radiology and Radiological Science, Medical University of South Carolina, Charleston, SC 29425, USA; [e] Institute for Clinical Radiology, Ludwig-Maximilians-University Hospital, Munich, Germany

* Corresponding author. Siemens Healthcare, Computed Tomography, Siemensstr. 1, Forchheim 91301, Germany.

E-mail address: thomas.flohr@siemens.com

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cardiac imaging in routine clinical scenarios.[7–10] While coronary CT angiography (CTA) and more refined imaging of the coronary anatomy have driven technical innovation in cardiac CT for the last 10 years, there is now an increasing focus on functional applications of cardiac CT, such as evaluation of the myocardial blood supply with first-pass enhancement studies, augmented by the use of dual-energy data acquisition, or dynamic myocardial perfusion assessment. These techniques may have the potential to enhance the application spectrum of cardiac CT, for example by providing means to determine the hemodynamic relevance of coronary artery stenosis. Furthermore, cardiovascular CT plays an increasing role in the support of interventions such as the planning of transcatheter aortic valve replacement procedures.

This article focuses on state-of-the-art CT imaging techniques to visualize the coronary anatomy, describes aspects of radiation dose reduction, and briefly touches on recent approaches to obtain functional information from a CT scan of the heart, in particular dual-energy CT.

CURRENT STATUS OF DATA ACQUISITION TECHNIQUES FOR CORONARY COMPUTED TOMOGRAPHIC ANGIOGRAPHY

Spatial Resolution

State-of-the-art ECG-controlled scanning of the heart with 64 or more slices with 0.5 mm, 0.6 mm, or 0.625 mm collimated slice width provides isotropic submillimeter resolution to visualize the coronary arteries. Despite the significant progress in comparison with older 4-slice or 16-slice technology, spatial resolution is still not fully sufficient for coronary CTA in patients with severe coronary calcifications. Calcium blooming may prevent reliable assessment of the coronary lumen and lead to overestimation of coronary artery stenosis. In a recent multicenter trial,[11] the presence of coronary calcifications with an Agatston score greater than 1000 was the most relevant independent predictor of uninterpretable coronary segments in a coronary CTA. Assessment of stent patency and in-stent restenosis is yet another challenge. Previous studies have shown that image quality is strongly dependent on the material and architecture of the stents, and on the technical properties of the CT system. Using 64-slice CT and first-generation dual-source CT (DSCT), Maintz and colleagues[12,13] found an average lumen visibility of 50% to 59% for most of the commonly used 2.5- to 4-mm coronary stents in a phantom setup, with extreme values of 3.3% for a tantalum stent and 90% for a magnesium stent. Ongoing technical progress may overcome some of the challenges posed by limited spatial resolution. Use of dedicated high-definition scan modes for the evaluation of 25 coronary stents resulted in significantly lower in-stent luminal attenuation and significantly larger mean measured in-stent luminal diameter.[14] Improved in-stent lumen assessment was demonstrated to be possible with third-generation DSCT.[15] Two previously evaluated stents[12,13] presented an in-stent lumen visibility of up to 76% and 83%, respectively, when scanned with a third-generation DSCT system, compared with respective visible diameters of 52% and 56.7% reported previously (**Fig. 1**).

Temporal Resolution

In CT, a partial scan data segment is the minimum amount of scan data needed for image reconstruction in the entire scan field of view (SFOV). A partial scan data segment comprises half a rotation of scan data plus the total detector fan angle. In the isocenter of the CT scanner, where the heart is usually positioned, half a rotation of scan data is sufficient. The data acquisition time per image, referred to as temporal resolution, is therefore half the gantry rotation time. Gantry rotation times down to 0.27 seconds with modern CT scanners result in a temporal resolution down to 135 milliseconds. This time is adequate for a clinically robust visualization of the coronary arteries at moderate heart rates, but may be challenging in patients with high and irregular heart rates. To improve temporal resolution, several approaches have been introduced. From the very beginning of cardiac CT multisegment reconstruction, the combination of smaller scan data segments from multiple consecutive heartbeats, has been

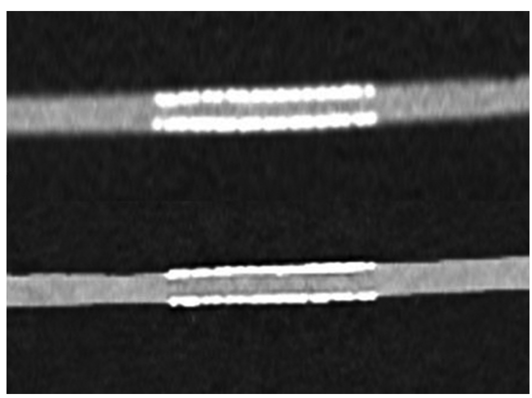

Fig. 1. A 3-mm stent in a contrast-filled tube, scanned on a 64-slice CT system (*top*) and on a third-generation dual-source CT (DSCT) system (*bottom*), applying the highest available spatial resolution. (*Courtesy of* T. Gassenmaier, MD, University of Würzburg, Würzburg, Germany.)

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