Current Clinical and Research Developments in Cardiovascular Multi-Detector Computed Tomography

P Schoenhagen

Cleveland Clinic, Cardiovascular Imaging

Computed tomography (CT) was introduced into medical imaging in the 1970s.[1] Across multiple medical specialties, it has since enabled novel diagnostic approaches for a variety of clinical conditions. Technical advances, including fast gantry rotation and multi-detector technology, subsequently allowed cardiovascular applications including imaging of the coronary arteries.[2,3]

Current multi-detector scanners allow fast data acquisition during continuous rotation of the gantry and continuous movement of the patient table ("spiral acquisition"). Data are acquired through the entire cardiac cycle during simultaneous recording of the ECG signal. State-of-the-art 64-detector scanners cover a few centimeters per rotation and therefore require 3-5 gantry rotations to cover the entire coronary tree. Following image acquisition, data from specific periods of the cardiac cycle (most commonly late diastole, when cardiac motion is the least) are reconstructed by retrospective referencing to the ECG signal ("spiral acquisition with retrospective ECG-gating").[4] Although the tube current (and therefore radiation exposure) is reduced outside the selected phase ("dose modulation"), the continuous x-ray exposure during the entire cardiac cycle results in an increased patient radiation dose.[5] Alternatively, data acquisition can be performed by selectively turning the x-ray tube on only in the selected phase, triggered by the ECG signal, and coordinated with stepwise advancement of table position. This acquisition mode is called "sequential imaging with prospective triggering" and has recently been described with current multi-detector scanners.[6] An important advantage is the lower radiation dose, because the x-ray exposure only occurs during the selected cardiac phase rather than throughout the entire cardiac cycle.

Scanners with significant further increase in the number of detectors will allow imaging of the entire heart in one rotation, therefore obviating the need to move the patient table. A recent study describes the initial experience with such a 320-detector row CT system.[7] The system has a craniocaudal coverage of 16 cm in a single gantry rotation, which allows coronary imaging in a single heartbeat in a majority of patients. This eliminates potential artifacts at the transitions zone between gantry rotations, which are still seen with current state-of-the-art 64-slice systems. Coupled with prospective image acquisition,[6,7] the radiation exposure appears to compare favorably to current CT systems.

Other recent technological developments include faster gantry rotation times, dual-source technology,[8] and more efficient detectors and are associated with improved image

Correspondence:
Paul Schoenhagen
Cleveland Clinic, Cardiovascular Imaging, Desk HB-6, 9500 Euclid Avenue
Tel. 216 445 7579 E-mail: schoenp1@ccf.org

quality. However, despite this technical evolution, imaging of the small, rapidly moving coronary arteries remains challenging because of the limited spatial and temporal resolution and impaired visibility of densely calcified segments, which are an integral part of advanced atherosclerotic lesions. Plaque calcification of the vessel wall frequently precludes accurate visualization of the artery lumen, because dense calcification of the plaque leads to overestimation of luminal stenosis ("calcium blooming artifact"). These limitations are reflected in the results of single and multi-center studies comparing coronary CT angiography (CTA) to conventional coronary angiography, which consistently demonstrate a high negative predictive value (i.e. ability to rule out significant disease), but a lower positive predictive value to identify high-risk lesions.[9,10]

Based on the accumulating experience, consensus guidelines for appropriate diagnostic use of CTA are evolving.[11] In contrast to conventional coronary angiography, which is most useful for symptomatic, higher-risk populations with suspected high-grade stenosis, CTA is recommended for intermediate risk populations, which are alternatively examined with stress testing. The diagnostic goal includes the identification or exclusion of luminal stenosis, but also assessment of long-term cardiovascular risk.[12,13] Risk assessment with CT is already established with non-contrast CT (calcium scoring), which has demonstrated a prognostic role of calcium burden independent of conventional risk factors in intermediate risk populations.[14,15] More recently CTA studies have demonstrated the potential of CTA to visualize calcified and non-calcified atherosclerotic plaque of the vessel wall[16-18]. CT atherosclerosis imaging is a major area of imaging research with CTA.

By simultaneously assessing luminal stenosis and plaque burden, CTA allows the description of atherosclerotic disease patterns.[19] A pattern of 'absence of disease' (no atherosclerotic plaque and no luminal stenosis) appears to be associated with a very low risk for future events. No further tests are necessary and risk factor modification should follow established preventive guidelines. A pattern of 'non-obstructive disease' (calcified or non-calcified plaque in the vessel wall with estimated <50% stenosis) is likely associated with intermediate risk. Depending on clinical suspicion, additional functional stress tests can be justified and this pattern should trigger a review of potentially more aggressive risk factor management. In patients with a pattern of "suspected obstructive disease' (suspected >50% luminal stenosis), calcified lesions frequently preclude precise quantification of luminal stenosis, and further evaluation of hemodynamic significance is necessary. The exclusion of hemodynamic significant stenosis should be based on initial correlation with functional stress test results in most patients.[20] If clinical symptoms, and stress testing suggest a high likelihood of significant stenosis, cardiac catheterization is justified. Only in a few, highly selected situations, in particular if proximal disease is identified, cardiac catheterization without stress testing appears appropriate. Lastly, the identification of significant plaque burden, regardless of the presence or absence of associated hemodynamic stenosis, requires a more aggressive approach to risk factor modification. The clinical significance of these disease patterns

and appropriate clinical management approach needs to be further evaluated and evidence-based data is necessary.[21] In particular, there is need for epidemiologic data correlating results from CTA to stress-testing,[22] and eventually clinical outcome.[23]

CTA is not recommended for low-risk population (screening) because of its associated radiation exposure, and contrast administration. The increased use of CT over the last decades has already been associated with a significant increase in radiation exposure with uncertain long-term implications.[24,25] There is also a risk of false-positive test results with potential for unnecessary down-stream procedures. CTA is not recommended in high-risk patients, where conventional angiography remains the test of choice and CTA would only confirm the subsequent need for catheterization.

Other indications are evolving. Examples are the potential use of CTA in patients presenting with chest pain in the emergency department.[26] CTA is also becoming a tool in atherosclerosis imaging research.[27] Similar to invasive modalities including IVUS, OCT, and non-invasive imaging with MRI, CT has potential to assess plaque burden and composition as an endpoint in clinical trials.

Beyond coronary imaging, there are many other clinical applications of cardiovascular MDCT, many of which are already clinical standard.[28,29] A particular innovative area of research is the planning of endovascular and surgical procedures based on advanced reconstructions of CT data. A distinct advantage of computed tomographic angiography (CTA) is the routine acquisition of high-resolution 3-D/4-D datasets. Modern, computer-based

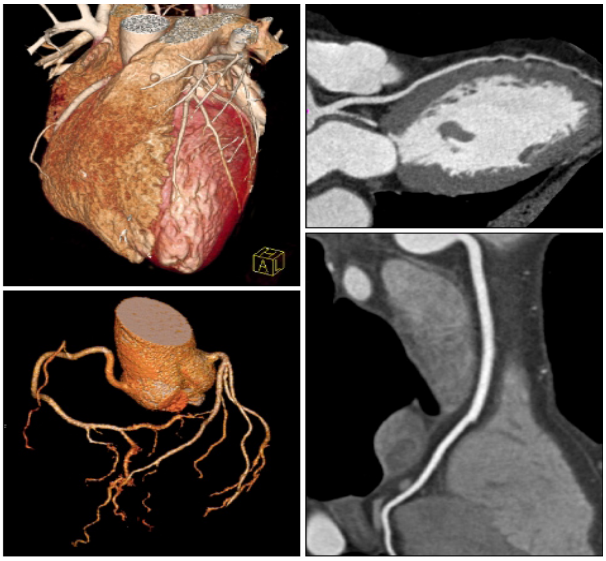

Figure 1: This figure shows MDCT images of the heart and coronary arteries. Volume-rendered images of the heart are shown on the left and curved MPR images of the coronary arteries are shown on the left.

analysis software allows unlimited oblique reconstruction for precise measurement in the axial plane and along the centerline of vascular structures. Additional volume-rendered images provide a 3-D/4-D display of complex cardiovascular anatomy. This information allows optimization of fluoroscopic view selection, planning of surgical access, guidance of device selection, and device customization. While data for coronary intervention is still limited,[30-32] the potential of image guidance has already been demonstrated by the experience with aortic endovascular stent procedures. Pre-procedural planning with CT is a critical part of clinical routine.[33,34] It is used for the design of custom-made stents,[35] which accommodate vessel tortuosity and side branches e.g. in the aorta arch and proximal abdominal aorta. More recently, this approach has been described in the context of novel surgical and interventional procedures, including hybrid surgical/endovascular procedures,

and robotic surgery.[36,37] Other clinical applications are stenting of the pulmonary veins after atrial fibrillation treatment,[38] reoperative cardiothoracic surgery[39] and most recently percutaneous aortic valve replacement.[40,41]

Imaging research will identify novel applications supporting innovative approaches to cardiovascular disease, including applications of nanotechnology in atherosclerosis imaging.[42] However, it is important to emphasize that the demonstration of technical feasibility is not equivalent to clinical utility. It is critical to match the rapid technological developments with a rigorous scientific evaluation. The ultimate goal will be to demonstrate an impact on clinical decision-making and eventually patient outcome.

Conflicts of Interest no declare.

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