

EDITORIAL COMMENT

Noninvasive Multi-Slice Computed Tomography Coronary Angiography

An Emerging Clinical Modality*

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X-ray angiography with selective contrast injection through cardiac catheterization remains the reference standard for the evaluation of the coronary arteries, but noninvasive alternatives, such as magnetic resonance imaging or computed tomography (CT), have been developed, the latter of which seems most robust for the detection of coronary stenosis at this moment.

Earlier reports using 4-detector row multi-slice computed tomography (MSCT) were promising, but the sensitivity and specificity to detect significant coronary stenosis, varying from 75% to 95% and from 84% to 98%, respectively, were achieved after the exclusion of coronary segments with inadequate image quality (1–5). Between 6% and 32% of the coronary segments were regarded as not interpretable as a result of cardiac or respiratory motion artifacts or severe calcifications and high heart rates.

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The current-generation 16-detector row CT scanners with a rotation time of 420 ms, in combination with heart rate control by beta-receptor blockers, seem to offer a dramatic improvement in image quality, quality consistency, and consequently diagnostic performance without exclusion of segments because of suboptimal image quality.

Ropers et al. (6) reported a sensitivity of 92% and a specificity of 93% but excluded 12% of the coronary segments because of inadequate image quality. Nieman et al. (7) demonstrated a sensitivity of 95% and a specificity of 86% by 16-slice MSCT in comparison with conventional angiography to detect significantly stenosed coronary arteries. In this report, none of the coronary segments were excluded from analysis.

In this issue of the *Journal*, Kuettner et al. (8) evaluated the diagnostic performance of 16-detector row MSCT in comparison with conventional angiography in a population of 58 symptomatic patients. Two patients were excluded from analysis. They also included patients who had undergone coronary artery bypass surgery, which made the inter-

pretation of the diagnostic performance of MSCT for the coronary arteries problematic. Much to their credit, they did not exclude any coronary segments from analysis based on the image quality. They reported a sensitivity of 72% and a specificity of 97% to detect significant stenoses, with conventional angiography as the standard of reference. These figures, which deviate from the earlier studies, could be the result of a different patient population (i.e., patients who underwent coronary artery bypass grafting, patients with a lower disease prevalence in terms of stenoses or calcium, patients who were older (>70 years of age), or patients who received less intensive beta-receptor blocking). Alternatively, these figures could be the result of a more exclusion-driven, rather than detection-driven evaluation and, therefore, merely represent another position on the same receiver-operator curve. They do confirm the observer-dependence of the visual and semiquantitative interpretation of CT angiograms and underline the urgent need for objective and accurate quantification tools.

Severe calcification remains to be a significant problem for the interpretation of CT angiograms and the detection of coronary stenosis. Kuettner et al. (8) stratified the results according to the coronary calcium score from a scan without contrast enhancement, which was acquired prior to the contrast-enhanced angiographic acquisition. As expected, the diagnostic performance was poor in patients with more extensive coronary calcification. In patients with limited coronary calcium (Agatston score <1,000) a sensitivity and specificity of 98% and 98% was achieved, compared with 58% and 87% in patients with a higher calcium score (Agatston score >1,000).

MSCT ASSESSMENT OF CORONARY BYPASS GRAFTS

Because of their larger diameter size and lesser mobility, coronary bypass grafts are more accessible to noninvasive evaluation. Evaluation of proximal graft patency has been demonstrated with electron-beam CT and spiral CT, whereas the evaluation of distal graft patency, disease at the insertion site, or nonocclusive graft stenoses have remained challenging (9–16).

In this issue of the *Journal*, Schlosser et al. (17) report on the noninvasive visualization of coronary artery bypass grafts using 16-detector row MSCT. They included 54 patients, 3 of whom were excluded because of irregular heart rhythm or fast heart rate despite beta-blockade. A total of 131 bypass grafts (40 internal mammary artery and 91 venous grafts) were available for evaluation.

All arterial graft conduits were accessible, although 26% of the distal anastomoses to the left anterior descending coronary artery and diagonal branch could not be evaluated as the result of poor opacification or artifacts caused by metal clips. Only four arterial grafts showed occlusive lesions, of which three were correctly detected, whereas all patent arterial grafts were correctly classified. All venous

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bypass grafts and proximal anastomoses were evaluable, although 26% of the distal anastomoses could not be evaluated. With respect to the patency of the evaluable venous grafts, the assessment by MSCT was entirely correct. Multi-slice computed tomography detected six nonocclusive stenoses, of which only a single case could be confirmed by conventional angiography. The sensitivity and specificity were 96% and 95%, respectively, after the exclusion of non-evaluable anastomoses. These results, as well as the case examples, illustrate the high image quality of MSCT, which allows the detailed evaluation of bypass grafts. However, to become a truly clinically useful tool in symptomatic patients after coronary artery bypass grafting, noninvasive imaging modalities should be able to evaluate the native vasculature, in addition to the bypass grafts, because disease progression in the coronary arteries could be responsible for reoccurrence of anginal symptoms as well (16). These patients often present after bypass with diffuse coronary artery disease and advanced calcification and are therefore more difficult to assess as may have been suggested by the results in the study by Kuettner et al. (8).

WHAT MAY WE EXPECT OF MSCT CORONARY ANGIOGRAPHY IN THE FUTURE?

First and foremost, MSCT technology must advance to overcome its most significant limitation, which is its susceptibility to residual motion artifacts, particularly in patients with a higher heart rate. Overcoming this limitation requires further acceleration of the X-tube rotation or other means to significantly improve the temporal resolution of the system. The current technology performs sufficiently in patients with a heart rate $<70 \text{ min}^{-1}$. Multi-segmental reconstruction algorithms, which combine isocardiophasic data from consecutive heart cycles to reconstruct each slice and improve the effective temporal resolution, or beta-receptor blockers for heart rate deceleration, will be required for interpretable image quality in those patients with a heart rate that exceeds 70 min^{-1} .

Although electron-beam CT lacks the spatial resolution and the number of detector rows of MSCT, it does provide data acquisition with a temporal resolution of 100 ms and less with the most recently introduced generation scanners. To what extent the respective advantages of either CT technology compensate for the disadvantages needs to be determined in comparative trials.

Luminal assessment in the presence of highly attenuating material such as calcium or stents seems somewhat improved with 16-detector MSCT but would further benefit from an increased spatial resolution and dedicated image reconstruction algorithms. Atrial fibrillation or other persistent arrhythmia that result in inconsistent end-diastolic ventricular volumes and consequently varying positions of the coronary arteries are not suited for the current CT technology, which requires a number of consecutive heart

cycles of approximately equal length to build up a complete coronary angiogram.

The considerable radiation exposure of MSCT (8 to 13 mSv) and, to a lesser extent of electron-beam CT (1.5 to 2.0 mSv), remains a matter of concern (18,19). Efforts by the manufacturers to reduce the exposure without compromise to the image quality are desired to accept CT coronary angiography as a truly less-harmful investigative tool.

WHAT WILL BE THE PLACE OF MSCT IN CARDIOLOGY PRACTICE?

We cannot and should not expect MSCT or other noninvasive modalities to equal the high quality and diagnostic versatility of conventional catheter-based coronary angiography. Instead, we need to determine when and how the advantages of these techniques (i.e., fast, relatively inexpensive, patient-friendly, and relatively harmless) should be exploited to benefit the management of patients with (possible) coronary artery disease. Whether MSCT is useful as a screening method in a selected patient population, as an alternative to exercise testing, myocardial perfusion, or dobutamine stress testing, or as an alternative to conventional angiography in patients with favorable characteristics (i.e., a regular heart rhythm with low heart rate and a low coronary calcium load, or in various other patient groups with differences in prevalence and clinical presentation varying from asymptomatic to stable, unstable angina, or acute myocardial infarction) needs to be evaluated in future trials.

The technological progress of MSCT coronary imaging during the past few years has been impressive, and we feel confident that continuing technical innovations will overcome many of the current limitations to advance clinical implementation of noninvasive coronary imaging. The question is not whether it is possible to replace diagnostic invasive coronary angiography but rather when; however, it may require several years to fully comprehend the role of MSCT in various clinical situations.

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