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EXPEDITED REVIEWS

Quantification of Obstructive and Nonobstructive Coronary Lesions by 64-Slice Computed Tomography

A Comparative Study With Quantitative Coronary Angiography and Intravascular Ultrasound

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OBJECTIVES The aim of the present study was to determine the diagnostic accuracy of 64-slice computed tomography (CT) to identify and quantify atherosclerotic coronary lesions in comparison with catheter-based angiography and intravascular ultrasound (IVUS).

BACKGROUND Currently, the ability of multislice CT to quantify the degree of coronary artery stenosis and dimensions of coronary plaques has not been evaluated.

METHODS We included 59 patients scheduled for coronary angiography due to stable angina pectoris. A contrast-enhanced 64-slice CT (Senation 64, Siemens Medical Solutions, Forchheim, Germany) was performed before the invasive angiogram. In a subset of 18 patients, IVUS of 32 vessels was part of the catheterization procedure.

RESULTS In 55 of 59 patients, 64-slice CT enabled the visualization of the entire coronary tree with diagnostic image quality (American Heart Association 15-segment model). The overall correlation between the degree of stenosis detected by quantitative coronary angiography compared with 64-slice CT was $r = 0.54$. Sensitivity for the detection of stenosis <50%, stenosis >50%, and stenosis >75% was 79%, 73%, and 80%, respectively, and specificity was 97%. In comparison with IVUS, 46 of 55 (84%) lesions were identified correctly. The mean plaque areas and the percentage of vessel obstruction measured by IVUS and 64-slice CT were 8.1 mm^2 versus 7.3 mm^2 ($p < 0.03$, $r = 0.73$) and 50.4% versus 41.1% ($p < 0.001$, $r = 0.61$), respectively.

CONCLUSIONS Contrast-enhanced 64-slice CT is a clinically robust modality that allows the identification of proximal coronary lesions with excellent accuracy. Measurements of plaque and lumen areas derived by CT correlated well with IVUS. A major limitation is the insufficient ability of CT to exactly quantify the degree of stenosis. (J Am Coll Cardiol 2005;46:147–54) © 2005 by the American College of Cardiology Foundation

A noninvasive method that would allow the evaluation of coronary stenoses with a comparable accuracy to catheter-based angiography would have enormous clinical value. The recent development of 16-slice computed tomography (CT) already constitutes an important step forward in noninvasive angiography and, although remarkable results to identify high-grade coronary stenoses were reported from several groups, it is evident that this technology is still affected by numerous limitations (1–5). Because of spatial resolution, the reliable identification of coronary lesions is restricted to major coronary branches with a diameter of at least 2 mm. Partial volume effects caused by coronary calcifications frequently count for false-positive and false-negative results. Furthermore, it is consistently reported that because of the limited temporal resolution, motion artifacts can only be avoided in patients with heart rates of <65 beats/min (3–7). Those limitations probably contributed to the fact that all existing studies focused on the detection of high-grade stenosis only and, until now, no attempt was directed toward a CT-derived stenosis quantification. For clinical purposes, however, it also is necessary to accurately determine the severity of a lesion because the therapeutic consequence of a 50% or a 90% stenosis may be completely different. The recent introduction of a new scanner generation with improved spatial and temporal resolution generating 64 slices per rotation and covering the entire volume of the heart in 8 to 9 s promises a significant improvement of image quality that may allow a more precise evaluation of coronary stenosis. Thus, the aim of the present study was to determine the diagnostic accuracy of a 64-slice CT that offers an isotropic voxel resolution of $0.4 \times 0.4 \times 0.4$ mm to identify and quantify atherosclerotic coronary lesions in comparison with catheter-based angiography and intravascular ultrasound (IVUS).

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Abbreviations and Acronyms

CSA	= cross-sectional area
CT	= computed tomography
EEM	= external elastic membrane
IVUS	= intravascular ultrasound
LAD	= left anterior descending artery
LCX	= left circumflex artery
MSCT	= multislice computed tomography
QCA	= quantitative coronary angiography
RCA	= right coronary artery

METHODS

Patients. From July to November 2004, we studied 59 consecutive patients (no previously known coronary artery disease [n = 49], patients with previous angioplasty [n = 10]) scheduled for conventional coronary angiography because of stable angina pectoris who were suitable for a 64-slice CT scan at least one day before the catheterization procedure. Patients with atrial fibrillation, previous bypass surgery, previous stenting of >1 vessel, an unstable clinical condition, or a contraindication to the administration of contrast agent were excluded. The 64-slice CT scan was performed within two days before coronary angiography in all patients. The study protocol included the oral administration of 50 mg of metoprolol 60 min before the scheduled CT scan in patients with heart rates >70 beats/min. However, in the presence of contraindications for a beta-blocker or an unsatisfactory lowering of the heart rate, the scan was performed even at higher heart rates. The study protocol was approved by the institutional ethics committee of the Grosshadern Hospital of the University of Munich, and all patients gave informed consent to participate in the study.

The 64-slice CT scanning technique. Computed tomographic angiography was performed using a 64-slice CT scanner (Sensation 64, Siemens Medical Solutions, Forchheim, Germany). A bolus of 80 ml of contrast agent (Solutrast 300, 300 mgI/ml^{-1}, Altana, Konstanz, Germany) was injected intravenously (5 ml/s^{-}). As soon as the signal in the ascending aorta reached a predefined threshold of 100 HU, the scan started automatically and the entire volume of the heart was acquired during one breathhold in 8 to 9 s with simultaneous recording of the electrocardiographic trace. The detector collimation was 0.6 mm, gantry rotation speed was 330 ms per rotation, tube voltage was 120 kV at a current of 550 to 750 mAs (depending on patient size) during 55% of the cardiac cycle (diastole), and a reduction of the current by 80% was performed during the remaining time of the R-R interval, leading to an estimated mean effective radiation dose of approximately 10 to 14 mSv. By applying a half scan algorithm (only data from a 180° gantry rotation is used for image reconstruction) in patients with heart rates <65 beats/min, acquisition time was reduced to 165 ms (gantry rotation time/2 = 330 ms/2). For heart rates >65 beats/min, the adaptive cardio volume mode was activated, which automatically switches from a one-segment to a two-segment scan (two segments from consecutive heart cycles that together provide data of a 180° rotation are used for slice reconstruction). Depending on the patient's heart rate, a maximum temporal resolution of 83 ms can be achieved (8,9). Using retrospective electrocardiographic gating, we performed routinely reconstructions at 500, 600, and 700 ms before the R-wave (10). Because of motion artifacts at these reconstructions, additional reconstructions at 300, 400, and 550 ms were performed in six patients.

Image analysis of 64-slice CT. The CT data set was analyzed by two independent experienced readers using the INSIGHT (Neoimagery Co., City of Industry, California) and the Leonardo (Siemens, Forchheim, Germany) software packages. In a first step, image quality was determined by the investigators on the basis of the presence of motion artifacts and on the basis of the contrast-to-noise ratio, as described in previous studies (11).

The grading criteria for image quality were as follows: A high-quality image was defined as no motion artifacts and a contrast-to-noise ratio of >8; a moderate-quality image was defined as motion artifacts present but the vessel still evaluable or a contrast-to-noise ratio between 4 and 8; and a poor-quality image was defined as motion artifacts present that made vessel delineation impossible or a contrast-to-noise ratio <4. Only patients who had high- and moderate-quality images of all coronary segments were considered for further analysis.

Any discernible structure that could be assigned to the coronary artery wall, that had a CT density less than the contrast-enhanced coronary lumen but greater than the surrounding connective tissue, and that could be identified in at least two independent planes was defined as a noncalcified coronary atherosclerotic plaque. Any structure with a density of 130 HU or more that could be visualized separately from the contrast-enhanced coronary lumen (either because it was "embedded" within noncalcified plaque or because its density was above the contrast-enhanced lumen), that could be assigned to the coronary artery wall, and that could be identified in at least two independent planes was defined as a calcified atherosclerotic plaque (12).

The display setting used for lumen and plaque quantification was determined empirically in a subset of six patients (recruited from the cohort of patients in whom IVUS was performed). In each patient, four different coronary sites that were easy to identify because of their location next to landmarks were selected. The image display setting at each site was then manipulated so that the multislice computed tomographic (MSCT) image equaled the IVUS image in size and pattern and allowed exact separation between vessel, surrounding tissue, plaque, and lumen. The values for window width and window level of the respective section were recorded and were set in relation to the mean intensity within the lumen at the corresponding site. The results of this analysis revealed that the optimal setting to detect plaque and outer vessel boundaries is obtained on average at a width representing 155% (range, 395