JACC: CARDIOVASCULAR IMAGING VOL. 1, NO. 2, 2008
© 2008 BY THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION ISSN 1936-878X/08/$34.00
PUBLISHED BY ELSEVIER INC. DOI:10.1016/j.jcmg.2007.11.006

Randomized Comparison of 64-Slice Single- and Dual-Source Computed Tomography Coronary Angiography for the Detection of Coronary Artery Disease

Stephan Achenbach, MD,* Ulrike Ropers, MD,* Axel Kuettner, MD,†
Katharina Anders, MD,† Tobias Pflederer, MD,* Sei Komatsu, MD,* Werner Bautz, MD,†
Werner G. Daniel, MD,* Dieter Ropers, MD*

Erlangen, Germany

OBJECTIVES The purpose of this study was to analyze the influence of a systematic approach to lower heart rate for coronary computed tomography (CT) angiography on diagnostic accuracy of 64-slice single- and dual-source CT.

BACKGROUND Coronary CT angiography is often impaired by motion artifacts, so that routine lowering of heart rate is usually recommended. This is often conceived as a major limitation of the technique. It is expected that higher temporal resolution, such as with dual-source 64-slice CT, would allow diagnostic imaging even without systematic pre-treatment for lowering the heart rate.

METHODS Two hundred patients with suspected coronary artery disease were first randomized to either 64-slice single-source CT (n = 100) or dual-source CT (n = 100) for contrast-enhanced coronary artery evaluation. In each group, patients were further randomized to either receive systematic heart rate control (oral and intravenous beta-blockade for a target heart rate ≤60 beats/min) or receive no premedication. Evaluability of datasets and diagnostic accuracy were compared between groups against the results obtained from invasive angiography.

RESULTS Systematic pre-treatment lowered heart rate during CT coronary angiography by 10 beats/min. Heart rate control significantly improved evaluability in single-source CT (93% vs. 69% on a per-patient basis, p = 0.005), whereas it did not in dual-source CT (96% vs. 98%). In evaluable patients, sensitivity to detect the presence of at least 1 coronary stenosis by single-source CT was 86% and 79%, respectively, with and without heart rate control (p = NS). For dual-source CT, it was 100% and 95%, respectively (p = NS). The rate of correctly classified patients, defined as evaluable and correct classification as to the presence or absence of at least 1 coronary artery stenosis, was significantly improved by heart rate control in single-source CT (78% vs. 57%, p = 0.04), whereas there was no such influence in dual-source CT (87% vs. 93%).

CONCLUSIONS Systematic heart rate control significantly improves image quality for coronary visualization by 64-slice single-source CT, whereas image quality and diagnostic accuracy remain unaffected in dual-source CT angiography. Improved temporal resolution obviates the need for heart rate control. (J Am Coll Cardiol Img 2008;1:177–86) © 2008 by the American College of Cardiology Foundation

From the *Departments of Cardiology and †Radiology, University of Erlangen, Erlangen, Germany. This study was partly supported by a grant from Budesministerium für Bildung und Forschung (BMBF), Germany. Robert Bonow, MD, served as Guest Editor for this paper.

Manuscript received August 21, 2007; revised manuscript received November 15, 2007, accepted November 19, 2007.

JACC: CARDIOVASCULAR IMAGING, VOL. 1, NO. 2, 2008
MARCH 2008:177–86

Spatial and temporal resolution of multi-detector computed tomography (MDCT) have increased steadily over the past years. Together with dedicated image reconstruction algorithms (1), this has made computed tomography (CT) imaging increasingly applicable for coronary artery imaging (2). A mean sensitivity of 93% and specificity of 96% on a per-segment basis and a mean sensitivity of 99% and specificity of 93% on a per-patient basis have been reported for the detection of coronary artery stenoses by 64-slice MDCT (3). Coronary CT angiography is considered clinically appropriate, particularly in certain clinical situations (4), with the aim to avoid invasive coronary angiography if CT imaging demonstrates the absence of hemodynamically relevant coronary lesions.

See page 187

However, even with the latest generation of 64-slice MDCT systems, up to 12% of coronary artery segments had to be excluded from analyses, because they were categorized as "not evaluable" (2); motion artifacts are a frequent reason for impaired evaluability. Motion artifacts are more pronounced at higher heart rates, which have been identified as a major predictor of reduced image quality (5–10). Consequently, heart rates of <65 beats/min or, optimally, <60 beats/min are usually suggested in order to achieve predictably good image quality (2,11,12). This often requires premedication with beta-blocker drugs, and next to concerns of side effects and logistic challenges, some patients cannot achieve the target heart rates despite pre-treatment.

ABBREVIATIONS AND ACRONYMS

CAD = coronary artery disease

CT = computed tomography

MDCT = multi-detector computed tomography

Use of dual-source 64-slice CT increases temporal resolution of MDCT. The system combines 2 arrays consisting of 1 tube and 1 detector each, arranged within the same gantry at a 90° offset, so that one-quarter rotation is sufficient to sample X-ray transmission data over 180° of projections (13). With a gantry rotation time of 330 ms, the system could achieve a temporal resolution of 83 ms in the center of rotation. Small trials have shown that dual-source CT allowed optimum diagnostic image quality in the vast majority of patients even at higher heart rates and without beta-blockade (14–17). The diagnostic accuracy of dual-source MDCT coronary angiography has not been systematically evaluated. As such we undertook a randomized comparison of 64-slice single- and dual-source CT for the detection of coronary artery stenoses in patients referred for the first diagnostic study for suspected coronary artery disease (CAD).

METHODS

Patients. The present study evaluated 200 patients referred to our institution for a first diagnostic coronary angiogram for suspected CAD. Patients with established coronary artery stenoses, previous coronary artery stents, or coronary bypass surgery were not included. Patients with nonsinus rhythm, impaired renal function (creatinine >1.5 mg/dl), or other contraindications to iodinated contrast agent or patients unable to achieve a breathhold of at least 10 s were excluded. The mean age of patients was 63 ± 11 years; their mean weight was 81 ± 15 kg and mean heart rate before any pre-medication was 76 ± 13 beats/min (Table 1).

Patient preparation. Patients were randomized to MDCT scanning either with single- or dual-source CT. Within each group of 100 patients, all patients were further randomized to CT scanning without specific medication to lower heart rate or to a systematic approach of heart rate control with a target heart rate of 60 beats/min or less. In patients without heart rate control, 64-slice single-source or dual-source CT was performed without additional pre-medication irrespective of heart rate. Long-term beta-blocker medication, however, was not terminated for the scan. Patients randomized to systematic heart rate control received 100 mg nonretarded atenolol orally 45 min before CT scanning, if their heart rate at rest was 60 beats/min or more in inspiration. If, after that preparation, the heart rate measured on the CT table in deep inspiration was still more than 60 beats/min, they received repeated doses of 5 mg metoprolol intravenous in 2-min intervals until the heart rate was ≤60 beats/min or until a total of 20 mg had been injected. Immediately before CT data acquisition, 0.8 mg tri-nitroglycerine was administered sublingually.

64-slice single-source CT. One hundred patients were scanned with a 64-slice single-source CT scanner (Siemens Sensation 64, Forchheim, Germany) with 330-ms rotation time as previously described (18). Contrast agent transit time was determined after 10-ml injection of contrast agent (Omnipaque 350, Schering AG, Berlin, Germany) followed by 50 ml saline solution, both at 5 ml/s. The volume dataset for coronary visualization was acquired in deep inspiration with 64 × 0.6 mm collimation, pitch of 0.2 (reduced to 0.18 for heart rates <45 beats/min), tube voltage of 120 kV, and a maximum tube current of 800 mAs. In

Table 1. Patient Characteristics

		Single-Source CT		Dual-Source CT	
	All	No HRC	HRC	No HRC	HRC
n	200	45	55	53	47
Male/female	114/86	17/28	23/22	35/18	29/18
Age (yrs)	63 ± 11	65 ± 11	65 ± 11	61 ± 11	63 ± 11
Weight (kg)	81 ± 15	80 ± 15	78 ± 15	84 ± 16	80 ± 14
Beta-blocker medication	93	—	50/55 (90%)	—	43/47 (92%)
Baseline heart rate (beats/min)	76 ± 13	77 ± 15	77 ± 13	74 ± 13	77 ± 10
Heart rate during CT (beats/min)	65 ± 13	70 ± 15	60 ± 8	69 ± 14	59 ± 10
Heart rate ≤60 beats/min during CT	83/200 (42%)	12/45 (26%)	30/55 (55%)	13/53 (25%)	28/47 (59%)
Scan length (mm)	121 ± 14	116 ± 14	120 ± 13	121 ± 14	123 ± 14
Scan duration (s)	11 ± 1.9	12 ± 1.2	12 ± 1.1	9.2 ± 1.9	10.7 ± 1.8
Radiation exposure* (mSv)	13.3 ± 3.0	13.0 ± 2.7	12.0 ± 2.0	14.5 ± 3.3	14.8 ± 3.5

*Effective dose.
CT = computed tomography; HRC = heart rate control.

patients with a heart rate <65 beats/min, electrocardiogram pulsing was used to limit the full tube current to a time window of 450-ms duration in diastole. Outside this window, tube current was reduced by 80% (19). Contrast agent was injected intravenously at a flow rate of 5 ml/s, and the duration of contrast injection was adapted to match the duration of data acquisition (between 50 and 80 ml). Cross-sectional images were reconstructed with 0.75-mm slice thickness, 0.4-mm increment, and a medium-sharp kernel ("B25f"). Images were initially reconstructed with a half-scan reconstruction algorithm (165-ms temporal resolution) with the data window centered at 65% of the RR interval. If any motion artifacts were present in the dataset, further datasets were reconstructed in 5% decrements and increments with the aim to visualize each coronary segment free of motion artifact in at least 1 dataset. For patients with a heart rate >65 beats/min, additional datasets were reconstructed with a bi-segmental reconstruction algorithm that combined CT data of 2 consecutive cardiac cycles to improve temporal resolution, if no motion-free data sets had been obtained with half-scan reconstruction.

64-slice dual-source CT. One hundred patients were scanned with a dual-source CT scanner (Siemens Definition) with 330-ms rotation time as previously described (14). The volume dataset for coronary visualization was acquired in deep inspiration with 2 × 64 × 0.6 mm collimation, pitch between 0.2 and 0.43 depending on heart rate (14), tube voltage of 120 kV, and a maximum tube current of 400 mAs/tube. Electrocardiogram pulsing was used to reduce tube current by 80% outside a time window between 30% and 75% of the cardiac cycle. Contrast flow rate was 5 ml/s, and the duration injection was adapted to match the duration of data acquisition, but not <50 ml was injected for scan times of 10 s or less (between 50 and 75 ml). Cross-sectional images were reconstructed with 0.75-mm slice thickness, 0.4-mm increment, and a medium sharp kernel ("B26f"). All images were reconstructed with a half-scan reconstruction algorithm with 83-ms temporal resolution in the center of rotation, initially with the data window positioned at 70% of the RR interval. If any motion artifacts were present in the dataset, further data sets were reconstructed in 5% decrements and increments with the aim to visualize each coronary segment free of motion artifact in at least 1 dataset.

Data evaluation. One observer—blinded to all clinical data of the patient, to the heart rate, and to use of beta-blocker pre-medication—evaluated all coronary CT angiography data sets with review of axial images, multiplanar reconstructions, and thin-slab maximum intensity projections. Data were evaluated for the presence of significant coronary artery stenosis within 17 coronary artery segments (modified 16-segment model of the American Heart Association [20], with segment 17 being the intermediate branch of the left coronary artery, if present). First, each coronary segment was classified as "evaluable" or "unevaluable." All evaluable segments were then visually assessed with respect to the presence of a stenosis exceeding 50% diameter reduction (Figs. 1 and 2).

Invasive angiography data sets were evaluated by an independent observer with quantitative coronary angiographic software (QuantCor.QCA, PieMedical Imaging, Maastricht, the Netherlands) to assess luminal narrowing in coronary lesions as well as coronary diameters. In segments with a diameter ≥1.5 mm, lesions with a luminal diameter stenosis exceeding 50% were considered to represent significant stenoses. Coronary segments with a diameter

JACC: CARDIOVASCULAR IMAGING, VOL. 1, NO. 2, 2008
MARCH 2008:177–86

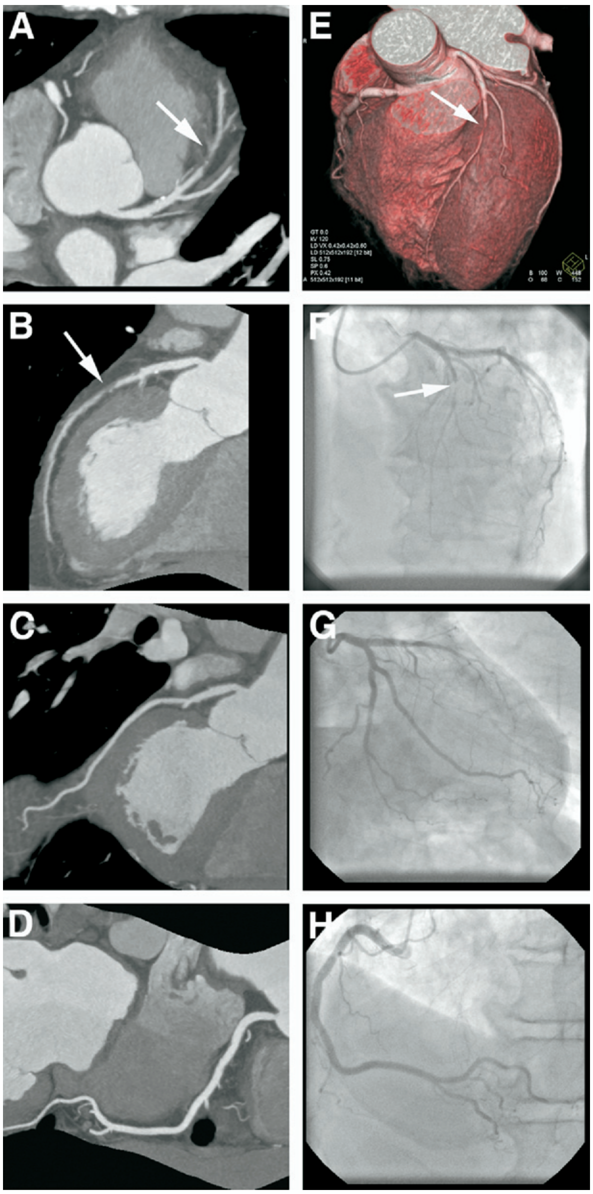

Figure 1. Coronary Artery Visualization by Dual-Source CT

Dual-source computed tomography (CT) angiography after intravenous injection of contrast agent. Heart rate was 47 beats/min with oral administration of 100 mg atenolol. **(A)** Transaxial maximum intensity projection shows the proximal left anterior descending coronary artery with a high-grade lesion **(arrow)**. **(B)** Curved multiplanar reconstruction of the left main and left anterior descending coronary artery (shows: high grade lesion) **(arrow)**. **(C)** Curved multiplanar reconstruction of the left main and left circumflex coronary artery. No stenoses are present. **(D)** Curved multiplanar reconstruction of the right coronary artery. No significant lumen reduction is present. **(E)** Three-dimensional rendering of the heart and coronary arteries. The high-grade lesion in the left anterior descending coronary artery is visualized **(arrow)**. **(F)** Invasive coronary angiogram of the left anterior descending coronary artery. A subtotal lumen narrowing with only very faint and slow filling of the distal segments is present **(arrow)**. Invasive angiogram of the left circumflex coronary artery **(G)** and right coronary artery **(H)** show no evidence of stenoses.

$<$1.5 mm and segments distal to a total coronary occlusion were not included in the analysis.

Statistical analysis. The primary form of evaluation was patient-based. A patient was considered "evaluable" if all coronary segments with a diameter $\geq$1.5 mm were evaluable and free of stenosis or if at least 1 stenosis had been detected by coronary CT angiography. Sensitivity, specificity, and negative and positive predictive values in "evaluable" patients were calculated for all 200 individuals as well as separately for patients studied by 64-slice single- and dual-source CT and further subdivided as to the use of systematic heart rate control. In addition, the percentage of correctly classified patients (evaluable and correctly classified as to the presence of at least 1 stenosis) was determined for each group. Sensitivity, specificity, and positive and negative predictive values as well as percentage of evaluable and correctly classified entities were also determined on a per-vessel and -segment basis.

To eliminate bias introduced by the fact that observations in several coronary arteries or several coronary segments of the same patient are not independent, we performed additional analyses of the proportion of correctly classified vessels and segments after random selection of 1 vessel/patient and 1 coronary artery segment/patient.

All nominal variables are given as mean $\pm$ SD and were compared between groups with Mann-Whitney rank-sum test. Chi-square test was used to compare categorical variables as well as sensitivities, specificities, and positive and negative predictive values. Values of $p \leq 0.05$ were considered to represent statistical significance.

Power analysis determined that, under the assumption that 95% of vessels would be evaluable with single-source CT and systematic heart rate control and to demonstrate a difference in the rate of evaluable patients of 25%, 100 randomized individuals would provide a statistical power of 0.7 at an alpha error of 0.05%.

RESULTS

Of the 200 patients included in the present study, 100 were randomized to scanning by 64-slice single-source CT and 100 to dual-source CT. In further randomization, within the single-source CT group, 55 patients were randomized toward systematic heart rate control; of these 55 patients, 50 received beta-blocker premedication and 5 patients had a baseline heart rate $\leq$60 beats/min. Within the dual-source CT group, 47 patients were randomized to systematic heart rate control; 43 of the 47 patients received beta-blocker premedication, and 4 patients had a baseline heart rate of ≤60 beats/min. Concerning patient age, weight, and baseline heart rate, there were no significant differences among the 4 groups of patients. The proportion of female patients was significantly higher in the 2 groups studied by single-source CT ($p < 0.001$) as compared with the patients studied by dual-source CT (Table 1). Mean heart rates were 60 ± 8 beats/min versus 70 ± 15 beats/min in the 2 groups of patients studied by single-source CT ($p = 0.0003$) and 59 ± 10 beats/min versus 69 ± 14 beats/min in patients studied by dual-source CT ($p = 0.0003$). Of 102 patients randomized to systematic heart rate control, 58 achieved the target heart rate (≤60 beats/min), whereas 44 did not (Table 1). The proportion of those who met the target heart rate was not significantly different between single- (55%) and dual- (59%) source CT ($p = 0.23$). The mean effective dose, derived from the dose–length product, was 13.3 ± 3.0 mSv for all patients, and there was no significant difference between the groups (Table 1).

Per-patient analysis. Table 2 presents the results of the per-patient analysis. Overall, 182 patients were classified as evaluable, and in evaluable patients, sensitivity for stenosis detection across all patients was 90%; 73 of 81 patients with at least 1 stenosis were detected by CT. Specificity was 85% as 86 of 101 patients without stenoses were correctly detected. Of the 200 patients; 159 (80%) were classified correctly by CT, demonstrating that they were considered evaluable and the correct diagnosis had been established by CT. Of the 18 patients classified as unevaluable, 7 had at least 1 stenosis in invasive angiography.

In patients studied by single-source CT, the rate of evaluable patients was significantly higher in patients randomized to systematic heart rate control as compared with those studied without heart rate control (93% vs. 69%, $p = 0.005$). In patients studied by dual-source CT, there was no difference in evaluability in the 2 groups (96% vs. 98%). Similarly, in patients studied by single-source CT, the rate of patients who were correctly classified was significantly higher if randomized to heart rate control (78% vs. 57%, $p = 0.04$), whereas in patients studied by dual-source CT, there was no significant difference (87% vs. 93%). There was a tendency toward higher sensitivities and specificities in patients studied by dual-source CT as compared with patients studied by single-source CT, but these differences were uniformly nonsignificant (Fig. 3).

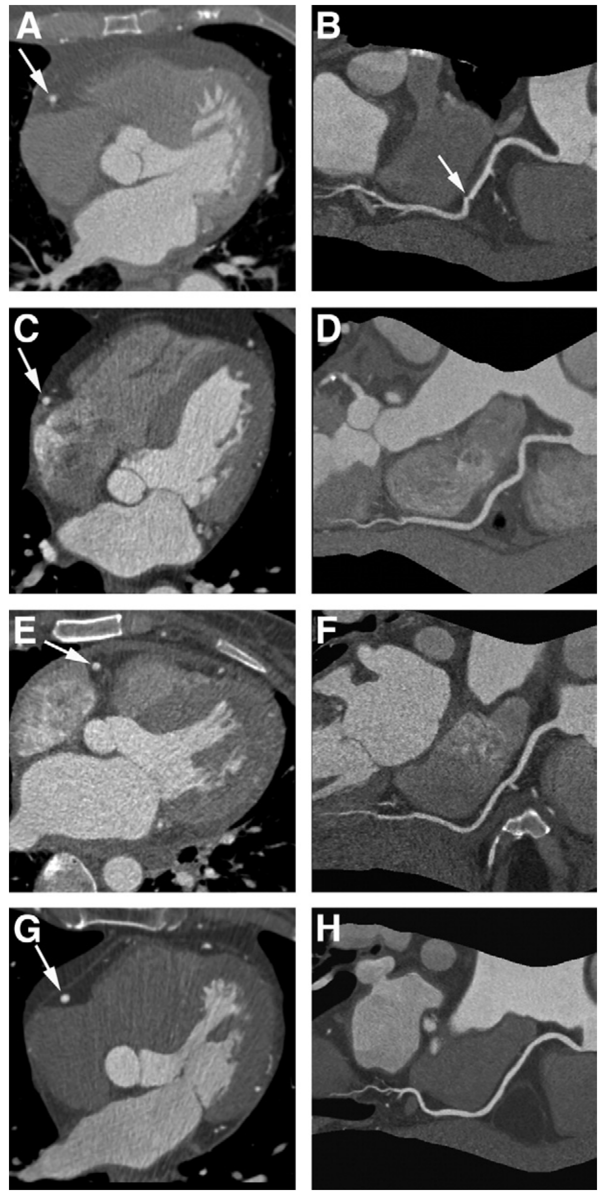

Figure 2. Comparison of Image Quality in the 4 Patient Subgroups

The image quality seen in the 4 patient subgroups is shown for a single- and dual-source computed tomography (CT) with and without systematic pretreatment to lower the heart rate. A transaxial cross-sectional image at the level of the mid right coronary artery and a curved multiplanar reconstruction are shown. Transaxial image **(A)** (**arrow** = right coronary artery) and curved multiplanar reconstruction of the right coronary artery **(B)** in a patient studied by a single-source CT without heart rate control. Heart rate was 78 beats/min; biphasic reconstruction was used. The **arrow in B** points at a typical misalignment artifact. Transaxial image **(C)** (**arrow** = right coronary artery) and curved multiplanar reconstruction of the right coronary artery **(D)** in a patient studied by a single-source CT with heart rate control. Heart rate during CT was 56 beats/min. Transaxial image **(E)** (**arrow** = right coronary artery) and curved multiplanar reconstruction of the right coronary artery **(F)** in a patient studied by dual-source CT without heart rate control. Heart rate during CT was 82 beats/min. Transaxial image **(G)** (**arrow** = right coronary artery) and curved multiplanar reconstruction of the right coronary artery **(H)** in a patient studied by dual-source CT with heart rate control. Heart rate during dual-source CT was 54 beats/min.

JACC: CARDIOVASCULAR IMAGING, VOL. 1, NO. 2, 2008
MARCH 2008:177–86

Table 2. Results of the Per-Patient Analysis

		Single-Source CT			Dual-Source CT			p Values		
	All	No HRC	HRC	p Value	No HRC	HRC	p Value	Single- vs. Dual-Source CT Without HRC	Single- vs. Dual-Source CT With HRC	Single-Source With vs. Dual-Source CT Without HRC
n	200	45	55		53	47				
Evaluable	182/200 (91%) (86%–94%)	31/45 (69%) (54%–81%)	51/55 (93%) (83%–97%)	0.005	52/53 (98%) (90%–100%)	45/47 (96%) (86%–99%)	NS	<0.001	NS	NS
Sensitivity*	73/81 (90%) (81%–95%)	15/19 (79%) (57%–92%)	19/22 (86%) (67%–95%)	NS	20/21 (95%) (77%–99%)	19/19 (100%) (83%–100%)	NS	NS	NS	NS
Specificity*	86/101 (85%) (77%–91%)	11/15 (73%) (48%–89%)	24/29 (83%) (66%–92%)	NS	29/31 (94%) (79%–98%)	22/26 (85%) (67%–94%)	NS	NS	NS	NS
Positive predictive value*	73/88 (83%) (74%–89%)	15/19 (83%) (61%–94%)	19/24 (79%) (60%–91%)	NS	20/22 (91%) (72%–98%)	19/23 (83%) (63%–93%)	NS	NS	NS	NS
Negative predictive value*	86/94 (92%) (84%–96%)	11/15 (73%) (48%–89%)	24/27 (89%) (72%–96%)	NS	29/30 (97%) (93%–99%)	22/22 (100%) (85%–100%)	NS	NS	NS	NS
Correctly classified†	159/200 (80%) (73%–85%)	26/45 (57%) (43%–71%)	43/55 (78%) (66%–87%)	0.04	49/53 (93%) (82%–97%)	41/47 (87%) (75%–94%)	NS	<0.001	NS	NS

*In evaluable patients. †Correctly classified: the proportion of patients who were classified as "evaluable" and correctly determined as to the absence or presence of at least 1 stenosis. For each value, the actual numbers, percentage, and 95% confidence interval are provided.
CT = computed tomography; HRC = heart rate control.

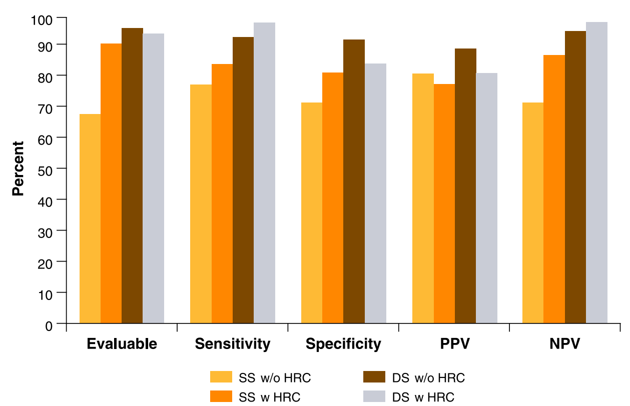

Figure 3. Comparison of the Rate of Evaluable Patients and Per-Patient Accuracy for Stenosis Detection on the 4 Patient Groups

The rate of evaluable patients was lower for single-source computed tomography (CT) without systematic pre-treatment to lower heart rate as compared with pretreatment to achieve a target heart rate ≤60 beats/min. Similarly, the lowest sensitivity, specificity, and positive predictive value (PPV), and negative predictive value (NPV) was found for the patients studied by single-source CT without systematic pretreatment to control heart rate, but these differences were not always significant (Table 2). DS = dual-source; HRC = heart rate control; SS = single source; w = with; w/o = without.

Per-vessel analysis. Table 3 presents the results of the per-vessel analysis. Of a total of 800 coronary arteries (i.e., left main, left anterior descending, left circumflex, and right coronary artery in 200 patients), 738 were considered evaluable by CT (92%). Of the 62 "unevaluable" arteries, 17 had a significant stenosis.

In patients studied by single-source CT, the rate of evaluable arteries was significantly higher in patients randomized to systematic heart rate control as compared with those studied without heart rate control (91% vs. 82%, p = 0.02). In patients studied by dual-source CT, there was no difference in evaluability in the 2 groups (96% vs. 98%). In patients studied by single-source CT, the rate of arteries that were correctly classified was significantly higher if randomized to heart rate control (86% vs. 77%, p = 0.03), whereas there was no significant difference in patients studied by dual-source CT (92% vs. 95%). There was a tendency, similar to the per-patient analysis, toward higher sensitivities and specificities in patients studied by dual-source CT as compared with patients studied by single-source CT, but in most instances these differences were not significant (Table 3).

After random selection of 1 vessel/patient, the proportion of correctly classified arteries in patients

Table 3. Results of the Per-Vessel Analysis

		Single-Source CT			Dual-Source CT			p Values		
	All	No HRC	HRC	p Value	No HRC	HRC	p Value	Single- vs. Dual-Source CT Without HRC	Single- vs. Dual-Source CT With HRC	Single-Source With vs. Dual-Source CT Without HRC
n	800	180	220		212	188				
Evaluable	738/800 (92%) (90%–94%)	149/180 (82%) (77%–88%)	200/220 (91%) (86%–94%)	0.02	208/212 (98%) (95%–99%)	181/188 (96%) (93%–98%)	NS	<0.001	0.002	0.048
Sensitivity*	101/115 (88%) (81%–93%)	17/25 (68%) (48%–83%)	24/27 (89%) (72%–96%)	NS	33/34 (97%) (85%–100%)	27/29 (93%) (78%–98%)	NS	0.007	NS	NS
Specificity*	599/623 (96%) (94%–97%)	121/124 (98%) (93%–99%)	164/173 (95%) (90%–97%)	NS	169/174 (97%) (94%–99%)	145/152 (95%) (91%–98%)	NS	NS	NS	NS
Positive predictive value*	101/125 (81%) (73%–86%)	17/20 (85%) (64%–95%)	24/33 (73%) (56%–85%)	NS	33/38 (87%) (73%–94%)	27/34 (79%) (63%–90%)	NS	NS	NS	NS
Negative predictive value*	599/613 (98%) (96%–99%)	121/129 (94%) (88%–97%)	164/167 (98%) (95%–99%)	NS	169/170 (99%) (97%–100%)	145/147 (99%) (95%–100%)	NS	0.01	NS	NS
Correctly classified†	700/800 (88%) (85%–90%)	138/180 (77%) (70%–82%)	188/220 (86%) (80%–90%)	0.03	202/212 (95%) (92%–97%)	172/188 (92%) (87%–95%)	NS	<0.001	NS	0.001

*In evaluable vessels. †Correctly classified: the proportion of vessels that were classified as "evaluable" and correctly determined as to the absence or presence of at least 1 stenosis in a coronary segment assigned to that artery. For each value, the actual numbers, percentage, and 95% confidence interval are provided.
CT = computed tomography; HRC = heart rate control.

scanned by single-source CT was 47 of 55 (90%) with systematic heart rate control versus 32 of 45 (71%) in patients without heart rate control ($p = 0.07$). For dual-source CT, the proportions were 44 of 47 (94%) versus 48 of 53 (91%) (p = NS).

Per-segment analysis. Table 4 lists the results of the per-segment analysis. A total of 2,868 coronary artery segments were present, after segments with a diameter <1.5 mm (n = 99) and segments distal to total occlusions (n = 28) had been excluded. Of these 2,868 segments, 2,644 were considered evaluable by CT (92%). Of the 224 unevaluable segments, 37 had a significant stenosis.

In patients studied by single-source CT, the rate of evaluable segments was significantly higher in patients randomized to systematic heart rate control as compared with those studied without heart rate control (93% vs. 82%, $p < 0.001$). In patients studied by dual-source CT, there was no difference in evaluability in the 2 groups (97% vs. 96%). However, the rate of evaluable arteries was significantly higher in patients studied by dual-source CT, regardless of whether they were randomized to heart rate control, than in patients studied by single-source CT with or without heart rate control. In patients studied by single-source CT, the rate of segments that were correctly classified was significantly higher if randomized to heart rate control (91% vs. 80%, $p < 0.001$), whereas there was no difference in patients studied by dual-source CT (95% in both subgroups). Again, the rate of correctly classified segments was significantly higher in both dual-source CT groups as compared with the 2 single-source CT groups. There was a tendency, similar to the per-patient and -vessel analysis, toward higher sensitivities and specificities in patients studied by dual-source CT as compared with patients studied by single-source CT, but in most instances, these differences were not significant (Table 4).

After random selection of 1 segment/patient, the proportion of correctly classified segments in patients scanned by single-source CT was 44 of 48 (90%) with systematic heart rate control versus 33 of 39 (85%) in patients without heart rate control (p = NS). For dual-source CT, the proportions were 44 of 45 (94%) versus 35 of 37 (95%) (p = NS).

DISCUSSION

In this randomized evaluation, we studied 200 patients by coronary CT angiography with 64-slice

Table 4. Results of the Per-Segment Analysis

		Single-Source CT			Dual-Source CT			p Values		
	All	No HRC	HRC	p Value	No HRC	HRC	p Value	Single- vs. Dual-Source CT Without HRC	Single- vs. Dual-Source CT With HRC	Single-Source With vs. Dual-Source CT Without HRC
n	2,868	671	809		743	645				
Evaluable	2,644/2,868 (92%) (91%–93%)	552/671 (82%) (79%–85%)	755/809 (93%) (91%–95%)	<0.001	711/743 (96%) (94%–97%)	626/645 (97%) (95%–98%)	NS	<0.001	0.002	0.05
Sensitivity*	133/155 (86%) (79%–90%)	19/29 (66%) (47%–80%)	33/39 (85%) (70%–93%)	NS	45/49 (92%) (81%–97%)	36/38 (95%) (83%–99%)	NS	0.009	NS	NS
Specificity*	2,456/2,489 (99%) (98%–100%)	518/523 (99%) (98%–100%)	702/716 (98%) (97%–99%)	NS	657/662 (99%) (98%–100%)	579/588 (99%) (97%–99%)	NS	NS	NS	NS
Positive predictive value*	133/166 (80%) (73%–86%)	19/24 (79%) (60%–91%)	33/47 (70%) (56%–81%)	NS	45/50 (90%) (79%–96%)	36/47 (80%) (66%–89%)	NS	NS	NS	NS
Negative predictive value*	2,456/2,578 (99%) (99%–99%)	518/528 (98%) (97%–99%)	702/708 (99%) (98%–100%)	NS	657/661 (99%) (99%–100%)	579/581 (100%) (99%–100%)	NS	NS	NS	NS
Correctly classified†	2,589/2,868 (90%) (89%–91%)	537/671 (80%) (77%–83%)	735/809 (91%) (89%–93%)	<0.001	702/743 (95%) (93%–96%)	615/645 (95%) (93%–97%)	NS	<0.001	0.001	0.009

*In evaluable segments. †Correctly classified: the proportion of segments that were classified as "evaluable" and correctly determined as to the absence or presence of a stenosis. For each value, the actual numbers, percentage, and 95% confidence interval are provided.
CT = computed tomography; HRC = heart rate control.

single- and dual-source CT equipment to determine differences in the performance for the detection of coronary artery stenoses. Patients were further randomized to systematic heart rate control with a target heart rate of 60 beats/min or less to analyze the influence of such a strategy both in single- and dual-source. Most importantly, we made the following observations: 1) a systematic approach with oral and intravenous beta-blocker medication allows achievement of a target heart rate ≤60 beats/min in approximately 55% to 60% of patients with suspected CAD; 2) the use of systematic heart rate control significantly improves evaluability and the rate of correctly classified patients in single-source CT coronary angiography; and 3) in dual-source CT, no difference was observed concerning evaluability or diagnostic accuracy in patients randomized to systematic heart rate control as compared with patients scanned without systematic heart rate control.

In general, our results agree with previous studies that demonstrated high diagnostic accuracy of 64-slice (single-source) CT if a systematic approach to lower the patient's heart rate before CT scanning is used (2,3,21). Previous studies have also demonstrated that heart rate is a determinant of image quality and influences diagnostic accuracy in coronary angiography by single-source CT (5,7–9). However, a beneficial influence of systematic premedication by beta-blockade has not yet been demonstrated in a randomized fashion. For dual-source CT, only small studies are available that have demonstrated a high rate of evaluable arteries even in conditions such as patients with higher heart rates or patients with known and severe CAD (14–17). However, in these small reports, the influence of systematic premedication on evaluability and diagnostic accuracy in dual-source CT has not been studied. We demonstrated that dual-source CT preserves a high rate of evaluable patients, arteries, and segments, even if no systematic approach to heart rate lowering is used. This might be a potentially important finding concerning clinical applications of coronary CT angiography, such as in patients who cannot receive specific premedication to lower heart rate, in patients in whom such premedication is logistically challenging, or in patients whose heart rate is not lowered sufficiently despite the use of premedication. Whereas our study was underpowered to unmask more subtle differences in diagnostic performance of the 2 subgroups of patients studied by dual-source CT, we did not find a difference in evaluability and rate of correctly classified patients at a sample size that was large enough to demonstrate significant differences in patients scanned by single-source CT.

The most likely mechanism for the better performance of dual-source CT in patients with high heart rates is its higher temporal resolution. Dual-source CT has a temporal resolution of 83 ms in the center of rotation, independent of heart rate. Although the temporal resolution of 16- and 64-slice single-source CT systems can be improved through multisegment reconstruction, which has been found advantageous in some but not all cases (22–24), potential downsides of this approach include varying effectiveness with heart rate and the fact that data acquired during consecutive cardiac cycles are averaged to generate each cross-sectional image.

Limitations of our study include the relatively small sample size and the use of only 1 observer. Also the influence of heart rate variability was not studied, and patients with arrhythmias were excluded. Prevalence of disease was low (44% of patients), and therefore the results might not be immediately extrapolated to other populations, such as patients with higher pre-test likelihood of disease, arrhythmias, implanted coronary stents, or previous bypass surgery. We did not perform a systematic analysis of the extent of coronary calcification and the influence of calcium burden on the accuracy for the detection of stenosis in the 4 subgroups. We also did not analyze whether post-processing time is longer in patients with higher heart rates. Theoretically, the higher prevalence of female individuals in the patient group studied by single-source CT might have be another confounder, but it is not likely to influence the results of our study.

Reprint requests and correspondence: Dr. Stephan Achenbach, University of Erlangen, Ulmenweg 18, 91054 Erlangen, Germany. *E-mail: Stephan.achenbach@uk-erlangen.de.*

REFERENCES

1. Kachelriess M, Ulzheimer S, Kalender WA. ECG-correlated image reconstruction from subsecond multi-slice spiral CT scans of the heart. Med Phys 2000;27:1881–902.
2. Achenbach S. Computed tomography coronary angiography. J Am Coll Cardiol 2006;48:1919–28.
3. Vanhoenacker PK, Heijenbrok-Kal MH, Van Heste R, et al. Diagnostic performance of multidetector CT angiography for assessment of coronary artery disease: meta-analysis. Radiology 2007;44:419–28.
4. Hendel RC, Patel MR, Kramer CM, et al. ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. J Am Coll Cardiol 2006;48:1475–97.
5. Leschka S, Wildermuth S, Boehm T, et al. Noninvasive coronary angiography with 64-section CT: effect of average heart rate and heart rate variability on image quality. Radiology 2006;241:378–85.
6. Hoffmann MH, Shi H, Manzke R, et al. Noninvasive coronary angiography with 16-detector row CT: effect of heart rate. Radiology 2005;234:86–97.
7. Herzog C, Arning-Erb M, Zangos S, et al. Multi-detector row CT coronary angiography: influence of reconstruction technique and heart rate on image quality. Radiology 2006;238:75–86.
8. Ghostine S, Caussin C, Daoud B, et al. Non-invasive detection of coronary artery disease in patients with left bundle branch block using 64-slice computed tomography. J Am Coll Cardiol 2006;48:1929–34.
9. Wintersperger BJ, Nikolaou K, von Ziegler F, et al. Image quality, motion artifacts, and reconstruction timing of 64-slice coronary computed tomography angiography with 0.33-second rotation speed. Invest Radiol 2006;41:436–42.
10. Brodoefel H, Reimann A, Burgstahler C, et al. Noninvasive coronary angiography using 64-slice spiral computed tomography in an unselected patient collective: effect of heart rate, heart rate variability and coronary calcifications on image quality and diagnostic accuracy. Eur J Radiol 2007; (ePub ahead of Print).
11. Poon M. Technology insight: cardiac CT angiography. Nat Clin Pract Cardiovasc Med 2006;3:265–75.
12. Gerber TC, Breen JF, Kuzo RS, et al. Computed tomographic angiography of the coronary arteries: techniques and applications. Semin Ultrasound CT MR 2006;27:42–55.
13. Flohr TG, McCollough CH, Bruder H, et al. First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol 2006;16:256–68.
14. Achenbach S, Ropers D, Kuettner A, et al. Contrast-enhanced coronary artery visualization by dual-source computed tomography—initial experience. Eur J Radiol 2006;57:331–5.
15. Johnson TR, Nikolaou K, Wintersperger BJ, et al. Dual-source CT cardiac imaging: initial experience. Eur Radiol 2006;16:1409–515.
16. Scheffel H, Alkadhi H, Plass A, et al. Accuracy of dual-source CT coronary angiography: first experience in a high pre-test probability population without heart rate control. Eur Radiol 2006;16:2739–47.
17. Leschka S, Scheffel H, Desbiolles L, et al. Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG-pulsing windowing. Invest Radiol 2007;42:543–9.
18. Ropers D, Rixe J, Anders K, et al. Usefulness of multidetector row spiral computed tomography with 64- × 0.6-mm collimation and 330-ms rotation for the noninvasive detection of significant coronary artery stenoses. Am J Cardiol 2006;97:343–8.

19. Hausleiter J, Meyer T, Hadamitzky M, et al. Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. Circulation 2006;113:1305–10.
20. Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1975;51 Suppl:5–40.
21. Hamon M, Biondi-Zoccai GG, Malagutti P, et al. Diagnostic performance of multislice spiral computed tomography of coronary arteries as compared with conventional invasive coronary angiography: a meta-analysis. J Am Coll Cardiol 2006;48:1896–910.
22. Dewey M, Müller M, Teige F, et al. Multisegment and halfscan reconstruction of 16-slice computed tomography for assessment of regional and global left ventricular myocardial function. Invest Radiol 2006;41:400–9.
23. Dewey M, Laule M, Krug L, et al. Multisegment and halfscan reconstruction of 16-slice computed tomography for detection of coronary artery stenoses. Invest Radiol 2004;39:223–9.
24. Herzog C, Nguyen SA, Savino G, et al. Does two-segment image reconstruction at 64-section CT coronary angiography improve image quality and diagnostic accuracy? Radiology 2007;244:121–9.