Dual-Source Versus Single-Source Cardiac CT Angiography: Comparison of Diagnostic Image Quality

Robert Donnino[1]
Jill E. Jacobs[2]
Jay V. Doshi[3]
Elizabeth M. Hecht[2]
Danny C. Kim[2]
James S. Babb[2]
Monvadi B. Srichai[2]

OBJECTIVE. Dual-source CT improves temporal resolution, and theoretically improves the diagnostic image quality of coronary artery examinations without requiring preexamination ß-blockade. The purpose of our study was to show the improved diagnostic image quality of dual-source CT compared with single-source CT despite the absence of preexamination ß-blockade in the dual-source CT group.

MATERIALS AND METHODS. We performed a retrospective analysis of consecutive patients who underwent coronary artery evaluation with either single-source CT or dual-source CT at our institution between February 2005 and October 2006. Examination reports were analyzed for the presence of image artifacts, and image quality was graded on a 3-point scale (no, mild, or severe artifact). Type of artifact (motion, calcium, quantum mottle) was also noted.

RESULTS. Examinations (339 single-source CT and 126 dual-source CT) of 465 patients were analyzed. Artifact was reported in 39.8% of examinations using single-source CT and in 29.4% of examinations using dual-source CT ($p < 0.05$). The number of examinations with motion artifact was significantly higher with single-source CT than with dual-source CT (15.9% vs 4.8%; $p < 0.001$) despite significantly higher heart rates in the dual-source CT group (59.4 ± 8.4 vs 68.6 ± 14.6 beats per minute; $p < 0.001$). No patients in the dual-source CT group received preexamination ß-blockade compared with 81% of patients in the single-source CT group. The presence of severe (nondiagnostic) calcium artifact was also significantly reduced in the dual-source CT group (13.0% vs 3.2%; $p < 0.001$).

CONCLUSION. Dual-source CT provides significantly better diagnostic image quality than single-source CT despite higher heart rates in the dual-source CT group. These findings support the use of dual-source CT for coronary artery imaging without the need for preexamination ß-blockade.

Keywords: cardiac CT, coronary CT angiography, CT, dual-source CT, image quality

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[1]Department of Medicine, New York University School of Medicine, NYHHA VA Manhattan, 423 First Ave., 12 West Cardiology, New York, NY 10010. Address correspondence to R. Donnino (donnir01@nyumc.org).

[2]Department of Radiology, New York University School of Medicine, New York, NY.

[3]Department of Medicine, North Shore University–Long Island Jewish Medical Center, Manhasset, NY.

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Coronary artery disease (CAD) is a leading cause of morbidity and mortality in the United States and the world. The ability to noninvasively evaluate the coronary arteries has been limited by their small size and constant motion. Recently, MDCT has emerged as a noninvasive imaging technique for the evaluation of CAD. Initial cardiac CT angiography studies using 4-MDCT scanners were limited by several factors, including long breath-hold times (up to 40 seconds), poor temporal resolution (500 milliseconds) and suboptimal image quality [1, 2]. With this early technology, as many as 27–32% of coronary artery segments were not assessable [3, 4]. Early reports identified high heart rates as a significant factor contributing to reduced image quality [5, 6]. Continued improvements in single-source scanner technology have resulted in improved temporal resolution to as low as 165 milliseconds with 64-MDCT technology and decreased breath-hold times to approximately 8–15 seconds. Additionally, the use of ß-blockers in patients with heart rates faster than 60 beats per minute has been shown to further improve image quality and decrease motion artifacts [7]. Unfortunately, the routine administration of ß-blockers before scanning can be cumbersome and slow patient throughput. Despite these advances in MDCT technology, recent studies continue to report a significant number of coronary segments that are not assessable [8, 9]. Further improvements in temporal resolution could decrease motion artifacts, thereby improving image quality and potentially obviating ß-blockade before scanning.

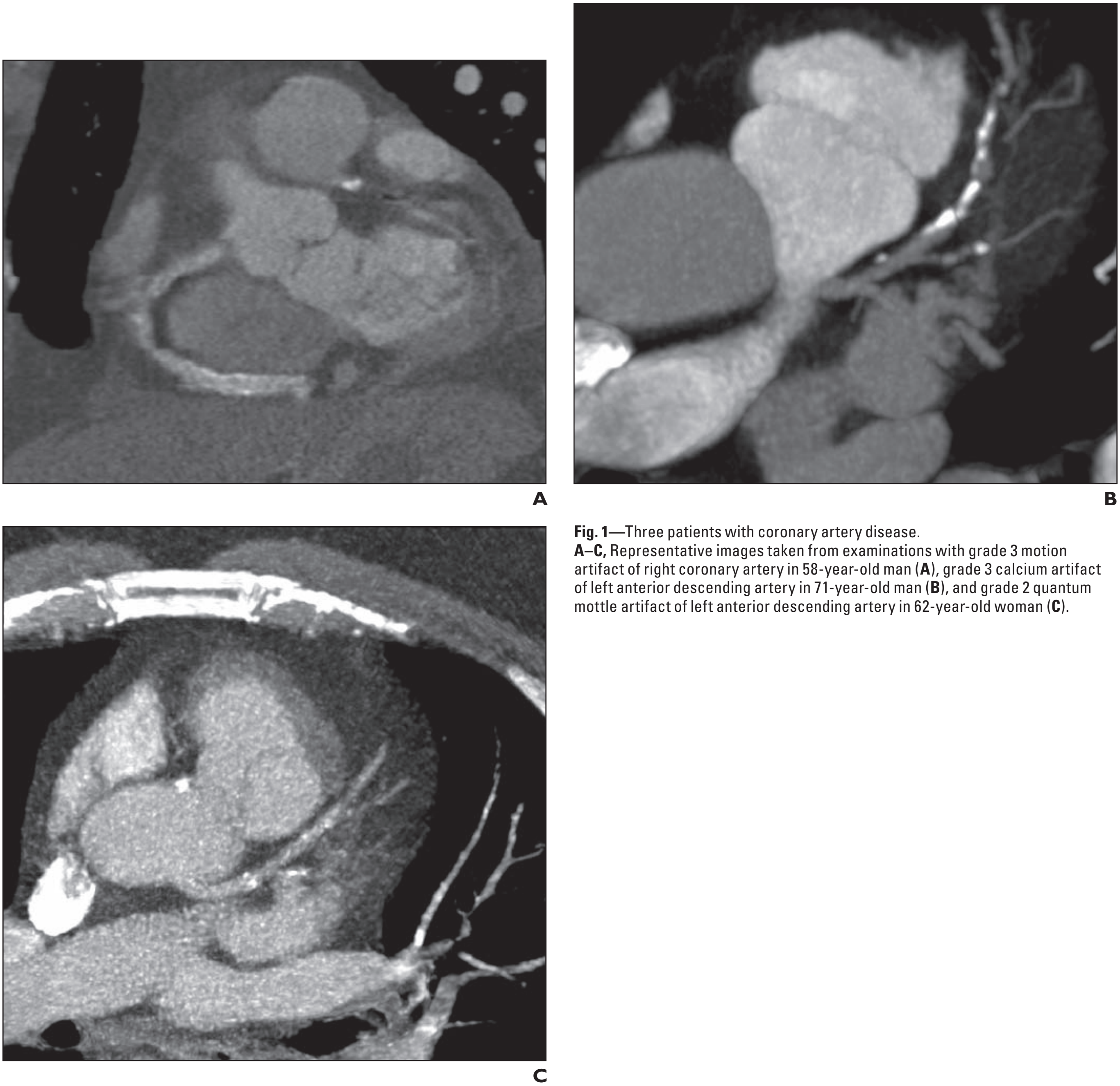


Fig. 1—Three patients with coronary artery disease.
A–C, Representative images taken from examinations with grade 3 motion artifact of right coronary artery in 58-year-old man (**A**), grade 3 calcium artifact of left anterior descending artery in 71-year-old man (**B**), and grade 2 quantum mottle artifact of left anterior descending artery in 62-year-old woman (**C**).

Dual-source CT has recently become clinically available and can be used to further improve temporal resolution. This technology uses two x-ray tubes and two detectors arranged at 90° angles, allowing reconstruction of cross-sectional images at one quarter of the gantry rotation time (330 milliseconds), thus improving temporal resolution to 82.5 milliseconds. Early studies reporting initial experience with dual-source CT show that good diagnostic image quality can be achieved in patients with relatively fast heart rates without the use of ß-blockade [10–14]. Our study aims to directly compare the diagnostic image quality obtained with a single-source CT scanner with that obtained using a dual-source CT scanner. We hypothesized that the image quality of the dual-source CT scanner would be superior to that of the single-source CT scanner despite the lack of ß-blocker administration in the patients undergoing dual-source CT.

Materials and Methods

Study Population

All patients included in this study were referred to our institution for coronary CT angiography to assess the presence of coronary artery disease or anomalies between February 2005 and October 2006. Patients were included only if they were older than 21 years and signed informed consent authorizing their records to be included in our coronary CT angiography research registry. Exclusion criteria included any patient with any of the following: prior coronary artery bypass surgery, intracoronary artery stent, mechanical prosthetic valve, or a paced rhythm. Although patients with irregular cardiac rhythms before CT acquisition were not scanned (as described in the following text), unexpected arrhythmias, such as frequent ectopy, did occasionally occur during the CT acquisition. If, despite optimal editing techniques, the arrhythmia was reported as significantly affecting image quality by the interpreting physician at the time of the scan, these examinations were excluded from analysis. This study was HIPAA-compliant and was approved by our institutional review board.

Study Design

We performed a retrospective analysis of the dictated clinical reports of all patients who underwent cardiac CT angiography and met the previously described criteria. The reports, dictated at the time of each examination, evaluated each coronary artery segment based on the American Heart Association 15-segment model [15]. Coronary artery plaques were characterized as calcified, noncalcified, or mixed, and the associated degree of luminal stenosis was reported when possible. The reports were analyzed for diagnostic limitations due to the presence of any image artifacts; when artifacts were present, they were classified by type and severity. Image quality was graded on a 3-point scale: grade 1 images contained no artifact, grade 2 images were those degraded by artifact that did not preclude evaluation of luminal stenosis, and grade 3 or nondiagnostic images were those that were severely degraded by artifact that precluded the evaluation of luminal stenosis. All artifacts were then classified as being due to motion (respiratory or cardiac), coronary calcification, or body habitus (i.e., quantum mottle artifact) (Fig. 1). Analyses were performed on a per-patient basis, meaning that examinations were considered to contain artifact if any one of the 15 coronary vessel segments displayed image degradation. If more than one type of artifact was present in a single examination, the scan was recorded as having both (or all three) artifacts present. If multiple vessel segments in a single examination contained artifacts of the same type, the scan was classified by the most severely graded artifact.

Image Acquisition

Coronary CT angiography was performed using either a dual-source 64-MDCT system (Somatom Definition, Siemens Medical Solutions) or a single-source 64-MDCT system (Somatom Sensation 64, Siemens Medical Solutions). The acquisition protocols described below were standard clinical protocols used at our institution and were the same for both scanners except when otherwise stated.

For patients on both systems, 18- or 20-guage IV access was obtained, and ECG leads were placed before the scans. ECG monitoring was continuous throughout each examination. As determined by the operating physician, the CT examination was cancelled if the ECG revealed an irregular rhythm. All patients underwent an initial gated, unenhanced CT scan to evaluate coronary artery calcification, and an Agatston calcium score was calculated for each patient using a cutoff of 130 HU to delineate calcification. At the discretion of the interpreting physician, any examination thought to contain too much calcium for clinical evaluation (based on total calcium and distribution) was cancelled, and no CT angiographic images were obtained; these patients were not included in our analysis.

Contrast-enhanced CT angiography was then performed using either Ultravist (iopromide, Bayer Schering Pharma, 370 mg I/mL) or Visipaque (iodixanol, GE Healthcare, 320 mg I/mL) as the IV contrast material at the discretion of the operator. Contrast material was injected at a rate of 4–6 mL/s and was immediately followed by a 40- to 50-mL saline bolus flush. Scan delay times were determined by either the test bolus or the bolus tracking method, using 10 mL of IV contrast material and monitoring peak enhancement in the ascending aorta. Volumetric data sets were acquired from the level of the carina through the diaphragm in a craniocaudal fashion during patient breath-holding using thin collimation (0.6 mm) and retrospective ECG gating. Tube voltage was 120 kV for single-source CT and 120 kV for each tube in the dual-source CT, and current was adjusted depending on scanning parameters and patient body habitus. All patients received 0.4 mg of sublingual nitroglycerine for optimal coronary imaging before each examination unless a contraindication existed (e.g., hypotension or known allergy).

Some differences did exist between single-source and dual-source acquisition. For single-source CT, pitch was set at 0.2 but was lowered to 0.18 for patients with heart rates less than 50 beats per minute, and ECG dose modulation was not used. For dual-source CT, pitch was automatically adjusted before scan acquisition depending on patient heart rate, and ECG dose modulation was used during all acquisitions, with a pulsing window of 30–80% of the R-R interval. During the remainder of the R-R interval, the tube current was reduced to 25% of the nominal output. Patients in the single-source CT group whose initial heart rates were faster than 60 beats per minute received a ß-blocking agent (oral or IV metoprolol) before the examination at the discretion of the operating physician. None of the patients in the dual-source CT group received a ß-blocker before their examination.

Image Processing

All image processing and interpretation were performed at the time of each scan. Images were reconstructed throughout the cardiac cycle (0–90% reconstructions of the R-R interval at 10% intervals) using a medium soft-tissue convolution kernel. The reconstruction phase with the least artifact was used to evaluate each vessel segment of at least 1.5 mm in diameter. Additional reconstructions were performed as needed to optimize image quality before generating the official report. ECG editing techniques were available for both scanners and were used at the operator's discretion. Studies were reviewed on a 3D workstation equipped with multiplanar and maximum-intensity-projection reformations by two readers in a consensus fashion. A total of four readers, each with a minimum of 2 years of experience reading coronary CT angiograms, were involved in image interpretation. Diagnostic limitations due to image quality and reason for limitations (e.g., motion artifact, calcium) were included in the official report. Additionally, analysis of left ventricular end-diastolic volume, end-systolic volume, and ejection fraction were routinely measured and included in official reports beginning in December of 2005.

Statistical Analysis

For statistical analysis the patients were divided into two groups—those whose examinations were performed with single-source CT and those whose examinations were performed with dual-source CT. To test our primary hypothesis, these groups were compared on the basis of the percentage of examinations that contained motion artifact of any degree (grade 2 or 3). In addition, we compared the groups with regard to the presence of calcium and quantum mottle artifacts. We also compared the groups on the basis of the presence of grade 3 artifact alone for all three types of artifact, although the study was not powered to detect differences at this level. A post hoc analysis dividing the patients into three groups based on heart rate < 65, between 65 and 75, and > 75 beats per minute, was performed, as described in prior reports [16].

Possible group differences for heart rate, Agatston calcium score, left ventricular ejection fraction, and examination protocol parameters were explored. Fisher's exact test and unpaired Student's *t* tests were used to compare categorical and continuous variables, respectively. Finally, multiple logistic regression analysis was performed to evaluate possible confounding variables. Results were considered to be statistically significant when p was less than 0.05. Statistical analyses were performed using SPSS version 13.0 (SPSS). Continuous variables are reported as mean ± SD.

Results

In total, 698 scans were performed, with 465 meeting inclusion criteria and used for analysis: 339 examinations using single-source CT, and 126 examinations using dual-source CT. Examinations were excluded from this study because of refusal to sign consent (97 examinations), prior coronary stent placement (55 examinations), prior coronary bypass surgery (26 examinations), arrhythmias or paced rhythms (16 examinations), and mechanical valves (three examinations). Examinations were cancelled for an additional 36 patients because of a high degree of coronary calcium, and these patients were not included in the analysis—26 patients (7.5%) for single-source CT and 10 patients (7.4%) for dual-source CT. Baseline characteristics of age, sex, and body mass index were similar for each of the two groups (Table 1). No significant difference was seen between groups with regard to total Agatston calcium score, nor was a difference seen in the number of patients in each group with calcium scores > 400 units (Table 1).

Overall, some degree of artifact (either grade 2 or 3) was reported in 39.8% of examinations using single-source CT and in 29.4% of examinations using dual-source CT ($p < 0.05$). The number of examinations with any degree of motion artifact present was significantly higher with single-source CT than with dual-source CT (15.9% vs 4.8%; $p < 0.001$). Neither calcium nor quantum mottle artifacts differed between the single-source CT and dual-source CT groups (Fig. 2).

TABLE 1: Baseline Characteristics and Examination Data

Parameter	Single-Source CT (n = 339)	Dual-Source CT (n = 126)	p
Baseline characteristics			
Age (y)	57.3 ± 12.0	57.8 ± 12.3	NS
Body mass index	27.5 ± 5.2	27.6 ± 5.8	NS
Sex (% men)	64%	63%	NS
Examination data			
Heart rate (beats per minute)	59.4 ± 8.4	68.6 ± 14.6	< 0.001
Left ventricular ejection fraction (%)[a]	67.0 ± 8.2	71.5 ± 10.4	< 0.001
Calcium score[b]	156.7 ± 331.3	130.7 ± 249.0	NS
Patients with calcium score > 400 (% of total)[b]	13	12	NS

Note—NS = not significant.
[a]For ejection fraction: n = 159 for single-source CT and n = 121 for dual-source CT.
[b]For calcium score: n = 335 for single-source CT and n = 123 for dual-source CT.

Heart rates were lower in the single-source CT group than in the dual-source CT group (mean, 59.4 ± 8.4 vs 68.6 ± 14.6 beats per minute; $p < 0.001$), which was expected given the absence of ß-blocker administration in the dual-source CT group. Although no patients in the dual-source CT group received a preexamination ß-blocker, 81% of patients in the single-source CT group did receive a preexamination ß-blocker, consistent with scan protocols. Heart rates were predictive of the presence of motion artifact in both the single-source CT group ($r = 0.24$, $p < 0.001$) and the dual-source CT group ($r = 0.31$, $p < 0.001$). When patients were divided into three groups based on mean heart rate < 65, between 65 and 75, and > 75 beats per minute, a significant improvement was seen in image quality with dual-source CT at all heart rates (Fig. 3).

Limiting analysis to examinations with grade 3 artifacts (i.e., nondiagnostic examinations), no significant differences were seen between the two scanners with regard to grade 3 motion or quantum mottle artifacts, although very few examinations met these criteria (Table 2). The number of examinations with grade 3 calcium artifacts, however, was significantly higher in the single-source CT group than in the dual-source CT group (13.0% vs 3.2%; $p < 0.001$, Table 2) Among these patients with grade 3 calcium artifact, the mean calcium score was 493 ± 509 for single-source CT and 734 ± 603 for dual-source CT (p = not significant).

Left ventricular ejection fraction was calculated for 47% of the single-source CT patients and for 96% of the dual-source CT patients (reflecting a change in performing routine ejection fraction calculations at our institution beginning in December of 2005). Among the patients for whom ejection fraction was available, the single-source CT patients had signifi-

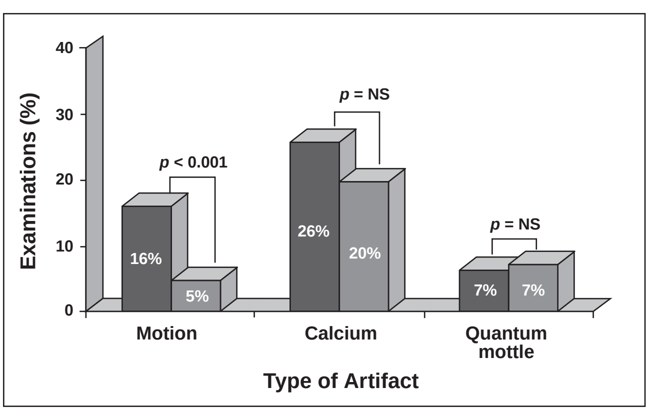


Fig. 2—Bar graph shows percentage of examinations with any degree of artifact. Dark gray indicates single-source data, and light gray indicates dual-source data. NS = not significant.

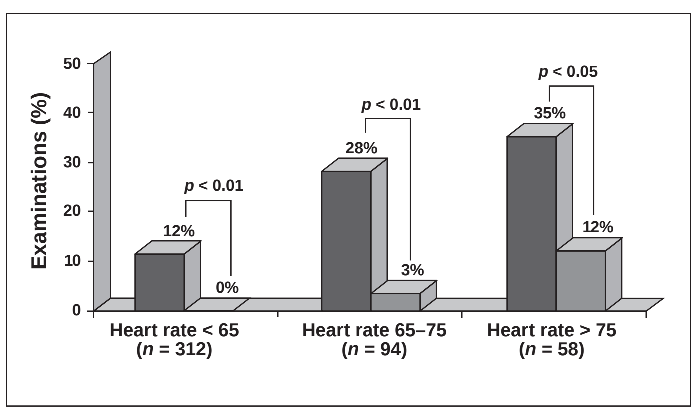


Fig. 3—Bar graph shows percentage of examinations with any degree of motion artifact. Dark gray indicates single-source data, and light gray indicates dual-source data.

cantly lower ejection fractions than the dual-source CT patients ($p < 0.001$, Table 1).

Differences in examination protocols are shown in Table 3. Logistic regression analysis was performed to adjust for differences in examination protocols between the single-source CT and dual-source CT groups. After logistic regression was used to adjust for contrast amount, contrast rate, saline bolus amount, and nitroglycerin administration, our primary finding of decreased motion artifact for dual-source CT remained statistically significant ($p < 0.001$), as did our finding of decreased grade 3 calcium artifact for the dual-source CT group ($p = 0.039$).

Discussion

This study confirms our primary hypothesis that, compared with single-source CT, dual-source CT showed improved image quality in coronary CT angiograms because of decreased motion artifact. This improvement was present despite the significantly higher heart rates that were observed in the dual-source CT group. Consistent with prior studies [17], our report shows a negative effect of increasing heart rate on image quality for both single-source CT and dual-source CT. On post hoc analysis, when the patients were divided into groups based on heart rate [16], image quality was improved for dual-source CT for all groups. Using dual-source CT, high-quality images were obtained even at patient heart rates greater than 100 beats per minute (Fig. 4). In addition, although dual-source CT showed better image quality than single-source CT at high heart rates, the image quality was even better at lower heart rates. In fact, motion artifact was not present on any of the dual-source CT examinations in patients with heart rates less than 65 beats per minute ($n = 55$). Thus, although this study confirms the ability of dual-source CT to obtain quality images without the use of preexamination ß-blockers, it also indicates that some benefit remains in imaging patients with slower heart rates. Our finding of improved image quality using dual-source CT

TABLE 2: Examinations Containing Grade 3 Artifact (i.e., Nondiagnostic Examinations)

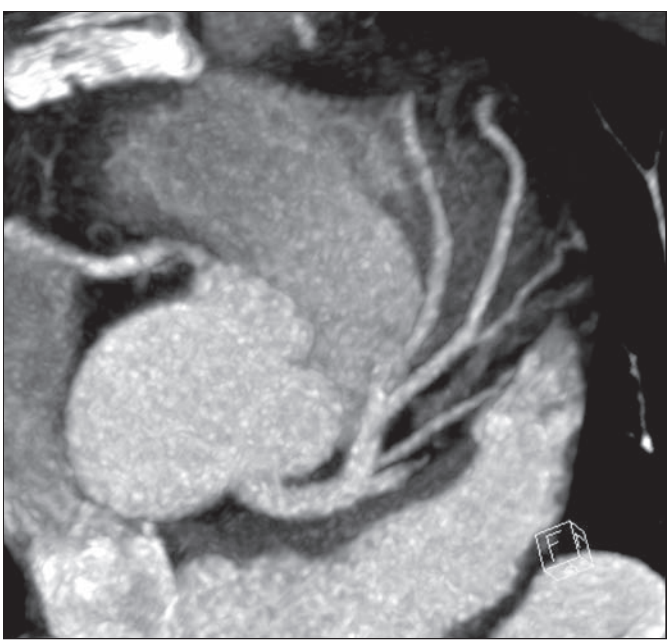
Type of Artifact	% of Examinations		p
	Single-Source CT ($n = 339$)	Dual-Source CT ($n = 126$)	
Any grade 3	15.6	6.4	< 0.01
Motion	2.6	< 1	NS
Calcium	13.0	3.2	< 0.001
Quantum mottle	< 1	2.4	NS

Note—NS = not significant.

TABLE 3: Examination Protocol

Parameter	Single-Source CT ($n = 339$)	Dual-Source CT ($n = 126$)	p
Nitroglycerin administration (% of total patients)	97	99	NS
β-blocker administration (% of total patients)	81	0	< 0.001
Contrast amount (mL)	84.2 ± 8.6	66.1 ± 9.8	< 0.001
Contrast rate of injection (mL/s)	4.5 ± 0.5	5.0 ± 0.2	< 0.001
Saline bolus chaser (mL)	41.3 ± 3.6	50.0 ± 0.0	< 0.001

Note—NS = not significant.



A

B

Fig. 4—57-year-old woman with heart rate greater than 100 beats per minute.
A, Maximum-intensity-projection image obtained with dual-source CT shows high-quality image of coronary arteries.
B, Three-dimensional volume-rendered image.

is consistent with smaller studies and anecdotal reports [11, 18]. A recent study comparing single-source CT and dual-source CT using coronary phantom models found improved image quality with dual-source CT across a wide range of simulated heart rates, consistent with the results of our study [19]. As anticipated, the number of scans with grade 3 (nondiagnostic) motion artifact was small, and this study was not powered to detect differences of only grade 3 motion artifact.

With regard to the other types of artifact that we analyzed, neither calcium artifact (grade 2 or 3) nor quantum mottle artifact (grade 2 or 3) differed between scanner groups. However, dual-source CT did show a significant reduction in nondiagnostic (i.e., grade 3) calcium artifacts compared with single-source CT. This finding was not due simply to the presence of more coronary calcification in the single-source CT patients because neither mean Agatston calcium scores nor the percentage of patients with scores > 400 units differed between groups.

Our data analysis also showed higher left ventricular ejection fractions in the dual-source CT group than in the single-source CT group. This may be due to the negative ionotropic effect of ß-blockade used exclusively in the single-source CT group. In addition, the improved temporal resolution of dual-source CT is more likely to capture the left ventricular volumes closer to true end-systole and end-diastole, which would result in higher calculated ejection fractions.

Study Limitations

One limitation of this study is its retrospective design. Patients were not randomly assigned to dual-source CT and single-source CT groups. Instead, examinations were obtained on whichever system was clinically available at the time of the study. After the installation of the dual-source CT at our institution in May 2006, most examinations (89%) were performed on this system. Conversely, all studies before May 2006 were performed using single-source CT. With this method of examination acquisition, it is possible that reader experience changed over time and played a role in the perceived improvement in image quality and artifact interpretation. In addition, without a fixed, prospective research protocol, examinations were carried out on the basis of current institutional protocols that were subject to slight variations over time. However, using logistic regression analysis to account for differences in examination protocols, our findings remained statistically significant.

That the readers were not blinded to the type of scanner used is another potential source of bias. Given the retrospective nature of this study, the readers' reports, dictated at the time of each scan, could not have been influenced by knowledge of this research study, which began after these images were analyzed and reported. However, this does not eliminate the possibility that knowledge of which scanner was being used may have unintentionally influenced artifact analysis. Finally, without an anatomic reference standard with which to compare CT angiograms (e.g., conventional fluoroscopic angiography, intravascular ultrasound, and so forth), we cannot confirm that the improved image quality led to more accurate diagnostic interpretations.

Conclusion

Dual-source CT showed a significant improvement in image quality over single-source CT, largely due to decreased motion artifact associated with the dual-source CT examination. This finding was true despite the absence of preexamination ß-blockade and significantly higher heart rates in the dual-source CT group. Additionally, severe calcium artifacts were significantly reduced with dual-source CT.

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