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Dual-Source Computed Tomographic Temporal Resolution Provides Higher Image Quality Than 64-Detector Temporal Resolution at Low Heart Rates

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Abstract

Objective—To compare coronary image quality at temporal resolutions associated with dual-source computed tomography (DSCT; 83 milliseconds) and 64-detector row scanning (165 milliseconds).

Methods—In 30 patients with a heart rate of less than 70 beats per minute, DSCT coronary angiograms were reconstructed at 83- and 165-millisecond temporal resolutions over different cardiac phases. A blinded observer graded coronary quality.

Results—The typical DSCT temporal resolution (83 milliseconds) showed a significantly greater quality at end-systole for all coronary vessels and at end-diastole for the right coronary and left anterior descending coronary arteries. For all vessels, the end-diastole produced the highest quality for both temporal resolutions.

Conclusions—Imaging at 83 milliseconds creates superior quality at end-systole for all coronary vessels and at end-diastole for the right coronary and left anterior descending coronary arteries. At low heart rates, end-diastole produces the highest quality at both temporal resolutions.

Keywords

CT; DSCT; coronary; temporal resolution; quality

In 64-detector row coronary computed tomographic angiography (CTA), a single x-ray source within the gantry rotates 360 degrees in 0.33 to 0.35 seconds (330–350 milliseconds), depending on the manufacturer. By using half-scan reconstruction, an effective temporal resolution of 165 milliseconds can be achieved near isocenter. Sixty-four-detector row scanners, operating with this temporal resolution, produce coronary images with very little motion degradation in patients with low heart rates (≤ 70 beats per minute [bpm]).¹ Furthermore, the sensitivity and specificity for detecting coronary stenoses, as compared with catheter angiography, have been very high in patients with low heart rates,² heart rates that have usually been achieved by premedicating patients with β -blocking medications.

Recently, the temporal resolution of 64–detector row scanners has been improved by mounting a second x-ray source and detector array pair on the gantry. Use of both x-ray sources and a gantry rotation time of 330 milliseconds allow the effective temporal resolution to be cut in half to 83 milliseconds.³ With this scanner type, known as a dual-source CT (DSCT) scanner, high quality images can be acquired in patients with higher heart rates than is possible on single-source 64–detector row scanners,⁴ and patients can be scanned with no β -blocker premedication.^{5,6} However, it is unknown whether DSCT provides incremental value over single-source 64–detector row CT in patients with low heart rates and, if so, over what portions of the cardiac cycle. Moreover, it would be helpful to make all of these comparisons from images collected at the same time in the same patient, to minimize physiologic variations that would occur from scanning at different times.

Therefore, the purpose of this study was to retrospectively compare coronary image quality at typical DSCT (83 milliseconds) and typical 64–detector row temporal resolutions (165 milliseconds) in patients with low heart rates, using data collected from the same patient at the same time. The second purpose was to determine the portion of the cardiac cycle with maximal coronary image quality for both types of images.

MATERIALS AND METHODS

Patient Selection

Institutional review board approval was obtained and patient information collected in compliance with the Health Insurance Portability and Accountability Act regulations. Thirty consecutive patients, who had undergone a clinically indicated DSCT coronary angiography, who had given authorization for retrospective research, and who had a mean heart rate of 70 bpm or less at the time of scanning, were included. Heart rate information was contained within the raw data of the scans from the electrocardiogram (ECG) acquired by the scanner. Patients who had undergone previous coronary artery bypass grafting were excluded to avoid artifacts from clips and difficulty in evaluating poorly opacifying native vessels.

Patient Demographic Information

A nurse not involved with CT image analysis reviewed the patients' electronic medical records for age, sex, height/weight, and body mass index.

Computed Tomographic Acquisition

All CTs were performed on a DSCT scanner (Siemens Definition; Siemens Medical Solutions, Forchheim, Germany). The CT parameters were as follows: tube potential, 120 kV; tube rotation, 0.33 seconds; acquisition mode, 64×0.6 mm; reconstruction slice width, 0.75 mm; reconstruction slice interval, 0.4 mm; kernel, B26f; and field of view, 25 cm. Electrocardiogram-based tube current modulation was enabled. Pitch varied with heart rate. Tube current was set based on the left-to-right width of the patient as measured at the dome of the liver on the scout image (Table 1).

Contrast material was injected through a peripheral intravenous line using a dual-head power injector (Stellant D; Medrad Inc, Warrendale, Pa). An iso-osmolar contrast material (Visipaque 320; Amersham Health Inc, Princeton, NJ; Food and Drug Administration approved) was injected at a rate that varied with patient weight as follows: patients weighing less than 50 kg were injected at 4 mL/s, 50 to 100 kg at 5 mL/s, and less than 100 kg at 6 mL/s.

The manufacturer's bolus tracking software, CAREbolus (Siemens Medical Solutions, Forchheim, Germany) was used with a region of interest placed over the ascending aorta.

Immediately before contrast injection, patients received a 1-time dose of sublingual nitroglycerin at 0.4 mg. No β blockade or other heart rate-controlling medications were administered.

The amount of contrast injected was calculated with the following formula: (scan time + 7) $\times$ injection rate = contrast dose. Therefore, for a patient with a scan time of 13 seconds and an injection rate of 5 mL/s, the initial bolus of contrast would be $(13 + 7) \times 5 = 80$ mL. Using the dual-head capability of the power injector, this initial bolus was immediately followed by a 40-mL mixture of 30% contrast and 70% saline, which was then followed by 10 mL of saline.

Computed Tomographic Reconstruction

For each patient, the DSCT data were reconstructed into 18 different series: 9 series reconstructed with typical DSCT temporal resolution (83 milliseconds) and 9 series reconstructed with typical 64-detector row temporal resolution (165 milliseconds).

First, a data set was created with information obtained from both x-ray sources, which is the commercially available algorithm. This allowed reconstruction of images with an 83-millisecond temporal resolution. From this data set, 9 image series were reconstructed, each at a different phase in the cardiac cycle starting at 30% and increasing at 5% increments until 70%. Phases from 0% to 25% and 75% to 100% were not reconstructed because those phases fell outside the window during which ECG-based tube current modulation used the full tube current. These images were reconstructed using a commercially available algorithm.

Second, a data set was created, which used only information obtained from 1 x-ray source, which was accomplished with the assistance of the manufacturer and was not, as performed here, commercially available. This 1 x-ray source data set allowed reconstruction of images with a 165-millisecond temporal resolution, which is equal to the temporal resolution of the 64-detector row CT scanner from the same manufacturer. From this data set, 9 image series were reconstructed, each at a different phase in the cardiac cycle starting at 30% and increasing at 5% increments until 70%.

Because the 83- and 165-millisecond images were reconstructed using the same total number of projections from the same scan data, the image noise was equivalent and there was no variability in patient conditions. The only difference between the 83- and 165-millisecond images was the use of 2 versus 1 x-ray source.

Each series was given a separate, randomized anonymous identification number. The images contained no information regarding patient identification, temporal resolution, or phase of the cardiac cycle.

Image Analysis

Images were reviewed by one observer with 7 years experience as a board-certified radiologist specializing in cardiac imaging. For each series, the reader was blind to patient information, temporal resolution of the images, and the phase of the cardiac cycle for which the images in that series had been reconstructed.

The reader used the American Heart Association 15 segment model (Fig. 1) to score the coronary arteries. For each segment, the reader gave a subjective score for coronary image quality of 0 to 4, with 0 representing minimal vessel quality (maximal vessel blurring) and 4 representing maximal vessel quality (Table 2). The quality score assigned to a coronary

segment represented the part of the coronary segment with the lowest quality/maximal blurring.

Using the American Heart Association 15 segment model, the coronary segments were then grouped into 4 coronary vessels: the right coronary artery (RCA), the left main coronary artery (LM), the left anterior descending coronary artery (LAD), and the circumflex coronary artery (Cx). For each vessel, the image quality score of the vessel was the mean of the scores of the segments comprising the vessel.

Segments 1 to 4 represented the RCA. For patients with left dominance, only segments 1 to 3 were used. Segment 5 was the LM. Segments 6, 7, and 8 represented the LAD. Segments 11, 12, and 13 represented the Cx. The remaining segments (9, 10, 14, and 15) represent diagonals, the second obtuse marginal, and the posterior descending in a left dominant system, which are inconsistently present or inconsistently visualized and were not included as parts of the LAD or circumflex for the purposes of this analysis.

Statistical Analysis

Summary statistics were reported for patient demographics (age, sex, body mass index, and heart rate).

For each observed phase of the cardiac cycle (30%–70%), the mean quality score of each coronary artery (RCA, LM, LAD, and Cx) was compared to determine if the 83-millisecond reconstruction produced statistically significant improved quality as compared with the 165-millisecond reconstruction for the given coronary artery.

Comparison of quality within a patient, at either the 83- or 165-millisecond reconstruction but at different phases, was made using generalized estimating equations to account for the correlation associated with measurements within the same patient.

Graphical analysis was also done to display the pattern of image quality for each of the 4 coronary artery types at various phases of the cardiac cycles for the 2 types of reconstructions. This was done using mean scores at each cardiac phase. This graphical approach also allowed us to visually assess the cardiac phases with best image quality at 2 different reconstructions of images (85 milliseconds vs 165 milliseconds). Repeated-measures analysis of variance was used to identify the phase of the cardiac cycle that had maximal coronary quality. The phase with the maximum quality was compared with other phases in a pairwise manner using paired *t* test. The phase(s) that were not significantly different from the best phase identified were reported. This was done separately for data collected at 85 and 165 milliseconds (Figs. 2 and 3).

RESULTS

Demographics

Patients were 19 men (63%) and 11 women (37%). Mean age was 56 years (range, 42–77 years). Mean (SD) heart rate for the group was 53.8 (8.7) bpm. Body mass index was 27.9 (3.9) kg/m². Indications for coronary CTA are summarized in Table 3.

Image Quality Is Superior at 83 milliseconds

The DSCT (83 milliseconds) reconstructions' quality was, in general, superior to the 64-detector rows' (165 milliseconds) quality. This is best seen in Figures 4–7, which plot image quality against phase of the cardiac cycle. The difference was statistically significant at end-systole (30%–40%) for all 4 vessels (Fig. 2) and at end-diastole (70%) for the RCA and LAD (Table 4).

Highest Quality Images Occur in Diastole

For both reconstructions, maximal image quality occurred in end-diastole (Figs. 3–7). For all 4 vessels, image quality showed a peak at end-systole (30%) and then declined during the onset of diastole, during which the ventricular cavities expand and coronary motion is rapid. Then, the coronary image quality increased and became maximal at end-diastole (65%–70%). The phases with maximal quality are summarized in Table 5, which shows that the end-diastolic phases (60%–70%) had statistically significant higher quality than the other phases.

DISCUSSION

In this study, we found that for patients with a low heart rate, coronary CTA with typical DSCT temporal resolution (83 milliseconds) had overall better image quality than typical 64–detector row temporal resolution (165 milliseconds). The difference was statistically significant at end-systole for all 4 vessels (RCA, LM, LAD, and CX) but was also statistically significant at end-diastole for 2 vessels (RCA and LAD). For all 4 vessels at both temporal resolutions, the maximal coronary image quality was at end-diastole.

The reason the DSCT temporal resolution (83 milliseconds) was superior at end-systole relates to coronary motion throughout the cardiac cycle. In the cardiac cycle, there are 2 relatively quiescent phases, 1 in end-systole and 1 in end-diastole. In patients with low heart rates, the end-systolic phase is shorter and is associated with more rapidly moving coronary arteries than the end-diastolic quiescent phase.⁷ Thus, increased temporal resolution would be more beneficial in the quiescent period at end-systole than the longer, slower-moving quiescent period at end-diastole. In the regions between the quiescent phases (45%–60%), cardiac motion is so fast that the 83-millisecond images are also degraded, negating the advantage of the better temporal resolution in these parts of the cardiac cycle.

It is important that for 2 vessels—the RCA and LAD—coronary image quality at 83 milliseconds was higher at end-diastole (70%), the phase with the best overall coronary image quality. Although it is known that at high heart rates, DSCT allows for superior image quality than attainable with 64–detector row scanning,⁴ our study shows that even in patients with low heart rates, scanning at 83 milliseconds improves image quality at least in 2 vessels (RCA and LAD).

Our findings confirm the findings of other studies that have shown that in patients with low heart rates, the best image quality for DSCT^{8–10} and 64–detector row scanners^{1,11,12} occur at end-diastole (60%–75%). Our study is unique in that previous studies have not attempted to compare DSCT (83 milliseconds) and 64–detector row (165 milliseconds) coronary artery quality and no studies to date have used different image reconstructions to compare images obtained from the same patient scanned at the same time.

There are several limitations to this study. The most important is lack of a reference standard to determine if the improved subjective coronary image quality lead to better sensitivity and specificity for detecting stenoses. In a retrospective study, Pugliese et al¹³ recently showed that in patients with optimal low heart rates, detection of stenoses with 16–detector row scanners was no different than that with 64–detector row scanners. Sixteen– and 64–detector row scanners have both shown excellent results in patients with very low heart rates. Although our study of patients with low heart rates shows an improved image quality in diastole in the RCA and LAD, it is not clear whether this will translate into clinically relevant outcomes, such as improved detection of stenoses.

A second limitation was our investigation of only the phases of the cardiac cycle from 30% to 70%. The patients were scanned with ECG-based tube current modulation, which optimizes image quality in selected portions of the cardiac cycle. In our case, we chose these phases to be from 30% to 70%. The remaining cardiac phases were acquired with lower tube current and thus would not be suitable for measuring image quality of coronary arteries. However, previous studies have shown that most phases outside this range are high motion and low quality and, therefore, should not affect the results of the study.

In conclusion, DSCT temporal resolution creates superior coronary image quality than 64-detector temporal resolution. The difference is significant not only at end-systole for all vessels, but also at end-diastole for the RCA and LAD. In patients with low heart rates, end-diastole produces the highest quality images for all vessels.

Acknowledgments

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FIGURE 1.
American Heart Association 15 segment model.

FIGURE 2.

Superior image quality of the 83-millisecond temporal resolution compared with the 165-millisecond temporal resolution in systolic phase. Axial ECG-gated DSCT images reconstructed at 40% of the R-R interval (systole) using the 83-millisecond (A) and 165-millisecond temporal resolutions (B). In this systolic phase, the RCA (arrow) has much better coronary image quality at 83 milliseconds (coronary image quality score, 4) than at 165 milliseconds (coronary image quality score, 0).

FIGURE 3.

Maximal coronary image quality at 65% reconstruction. Axial DSCT images at the 83-millisecond temporal resolution reconstructed at 35% (A), 50% (B), and 65% (C) of the R-R interval. In the 35% reconstruction, there is severe blurring of the RCA (arrow; coronary image quality score, 0). At 50%, there is minimal streaking and loss of quality of the RCA edges (arrow; coronary image quality score, 3). At 65%, the coronary image quality is maximal, with well-defined RCA edges (arrow; coronary image quality score, 4).

FIGURE 4.
Right coronary image quality versus cardiac phase.

FIGURE 5.
Left main coronary image quality versus cardiac phase.

FIGURE 6.
Left anterior descending coronary artery image quality versus cardiac phase.

FIGURE 7.
Circumflex coronary image quality versus cardiac phase.

TABLE 1

Patient Size–Specific Technique Chart to Determine Appropriate Milliampere Second

Patient Width at Level of Dome of the Liver, cm	Milliampere Second/Rotation
20.0–24.9	90
25.0–29.9	120
30.0–34.9	170
35.0–39.9	240
40.0–44.9	340
45.0–50.0	415

TABLE 2**Coronary Image Quality Scoring**

Score	Description
4 (Excellent)	Coronary walls are sharp and well-defined with no blurring. Calcifications in a segment show little or no streak. No discernible stairstep artifacts or discontinuity of the segment
3 (Good)	Coronary walls may be blurred, but lumen is clearly discernible and separate from the surrounding fat. Calcifications present may have small amount of streak. No discernible stairstep artifacts or discontinuity of the segment
2 (Fair)	Vessel walls may show mild streaking, but a defined lumen is identifiable. Calcifications may show mild streaking beyond the lumen of the vessel. A stairstep artifact may be detectable but should appear to cause little to no discontinuity of the segment
1 (Poor)	Severe streaking comprising more than 50% of the vessel lumen. Calcifications may streak beyond the vessel walls. May have a stairstep with clear discontinuity
0 (Extremely poor)	No definable lumen. If in cross section, vessel appears only as a blur. Vessels that run in plane may appear as multiple vessels. Calcifications do not appear as defined points. May have stairstep with major discontinuity

TABLE 3

Indications for Coronary CTA

Indication	n
Asymptomatic with coronary risk factors (screening for coronary artery disease)	8
Atypical angina	12
Shortness of breath or evaluation of new onset heart failure	4
Abnormal or equivocal stress test	5
Episode of sustained ventricular tachycardia, evaluate for coronary artery disease	1

TABLE 4
Coronary Image Quality at 83 milliseconds Compared With 165 milliseconds By Coronary Artery

Heart Phase, %	RCA		LM		LAD		CX	
	Estimate (SE)*	P	Estimate (SE)*	P	Estimate (SE)*	P	Estimate (SE)*	P
30	0.55 (0.17)	0.001	0.62 (0.18)	<0.001	0.83 (0.18)	<0.001	0.89 (0.18)	<0.001
35	1.07 (0.17)	<0.001	0.93 (0.18)	<0.001	0.69 (0.18)	<0.001	0.64 (0.18)	<0.001
40	0.68 (0.17)	<0.001	1.14 (0.19)	<0.001	0.78 (0.18)	<0.001	0.75 (0.18)	<0.001
45	0.43 (0.17)	0.012	0.64 (0.19)	<0.001	0.39 (0.18)	0.03	0.00 (0.18)	1.0
50	0.14 (0.17)	0.41	0.17 (0.18)	0.35	0.31 (0.18)	0.08	0.10 (0.17)	0.55
55	0.28 (0.17)	0.10	0.03 (0.18)	0.85	0.10 (0.18)	0.56	-0.18 (0.18)	0.31
60	0.07 (0.17)	0.67	0.19 (0.19)	0.33	0.25 (0.18)	0.17	0.11 (0.18)	0.54
65	0.21 (0.17)	0.21	0.39 (0.19)	0.04	0.25 (0.18)	0.17	0.21 (0.18)	0.23
70	0.46 (0.17)	0.006	0.29 (0.19)	0.13	0.36 (0.18)	0.047	0.21 (0.18)	0.23

* A positive estimate means that the coronary image quality score was higher (better) for 83 milliseconds.

TABLE 5

Cardiac Phases With Best Coronary Image Quality by Vessel

Phase With Maximal Image Quality (Mean)		All Phases With Image Quality Not Significantly Different From Maximal Quality Phase*
83 milliseconds		
RCA	70% (2.89)	65% (2.74)
LM	65% (3.33)	70% (3.31)
LAD	70% (2.66)	65% (2.60)
CX	70% (2.71)	65% (2.71)
165 milliseconds		
RCA	70% (2.55)	65% (2.51)
LM	70% (3.03)	65% (2.97) and 60% (2.87)
LAD	70% (2.38)	65% (2.37) and 60% (2.23)
CX	70% (2.55)	65% (2.53) and 60% (2.34)

* All phases not listed were significantly different from the phase with maximal quality.