

Does Two-Segment Image Reconstruction at 64-Section CT Coronary Angiography Improve Image Quality and Diagnostic Accuracy?¹

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Purpose:

To prospectively evaluate the effect of single- versus two-segment image reconstruction on image quality and diagnostic accuracy at 64-section multidetector computed tomographic (CT) coronary angiography by using conventional coronary angiography as the reference standard.

Materials and Methods:

The study design was approved by a human research committee; patients gave informed consent. The study was HIPAA compliant. Forty consecutive patients (22 men, 18 women; mean age, 61 years \pm 8 [standard deviation]) underwent both 64-section multidetector CT coronary angiography and conventional angiography. All data sets were reconstructed by using single- and two-segment image reconstruction algorithms, with resulting temporal resolution of 82.5–165 msec. Two experienced observers independently evaluated image quality and signs of coronary artery disease. A five-level grading scheme was used to grade stenosis (0%, <50%, <70%, <99%, 100%) and image quality (1[unacceptable] to 5[excellent]). Interobserver correlation, Spearman correlation coefficients, and diagnostic accuracy were calculated.

Results:

Six hundred coronary artery segments were visible on conventional angiograms, of which 560 (93.3%) were seen by using single-segment and 561 (93.5%) were seen by using two-segment image reconstruction ($P = .35$). Mean quality scores were not significantly different ($P = .22$) for single- (3.1 ± 0.9) and two-segment (3.2 ± 0.8) reconstruction. Significantly ($P = .03$) better image quality was observed for two-segment reconstruction only at heart rates of 80–82 beats per minute, at which temporal resolution was approximately 83 msec. For grading coronary artery stenosis, correlation was 0.64 for single- and 0.66 for two-segment reconstruction ($P = .43$). Significant stenosis (>50%) was detected on a per-segment basis with 77.1% sensitivity and 98.6% specificity by using single-segment and with 79.2% sensitivity and 99.1% specificity by using two-segment image reconstruction.

Conclusion:

At heart rates of more than 65 beats per minute, use of two-segment reconstruction improves image quality at multidetector CT coronary angiography but does not significantly affect overall diagnostic accuracy compared with single-segment reconstruction.

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In recent years, considerable interest has been directed at contrast material-enhanced computed tomographic (CT) angiography for noninvasive evaluation of coronary arteries (1–5). Particularly with the introduction of 64-section multidetector CT technology, CT is increasingly embraced as the noninvasive modality of choice for imaging coronary arteries (6–9).

However, according to results of studies (1–5) with four- and 16-section CT scanners, the overall accuracy of multidetector CT in the evaluation of coronary artery disease is still fairly low compared with that of invasive coronary angiography. One of the decisive advantages of conventional, or catheter, angiography for accurate stenosis assessment is its higher spatial resolution and temporal resolution far below 50 msec (10), which allow nearly motion-artifact-free imaging of almost every coronary segment during any phase of the cardiac cycle. Multidetector CT, with a temporal resolution that usually corresponds to half the gantry rotation time, strongly relies on correct positioning of the reconstruction interval within the R-R interval to suppress motion for sufficient image quality (11–14).

A widely applied strategy to improve temporal resolution at cardiac CT is the use of multisegment image reconstruction. With this approach, scanning data from more than one heart cycle are

used for the reconstruction of each transverse image (15,16). With current gantry rotation times of 350–330 msec, this approach results in a temporal resolution of 82.5–43 msec (two to eight segments) at some heart rates, compared with one of 175–165 msec for single-segment reconstruction (17–21). However, the practical value of segmented reconstruction is controversial. Previously published data (15,22) on potential improvements in image quality at coronary CT angiography with the use of multi- versus single-segment reconstruction disagree. More important, to our knowledge, the effect of segmented reconstruction algorithms on the actual diagnostic accuracy for lesion detection has not been addressed to date. The aim of our study, therefore, was to prospectively evaluate the effect of single- versus two-segment image reconstruction on image quality and diagnostic accuracy at 64-section multidetector CT coronary angiography by using catheter coronary angiography as the reference standard.

Materials and Methods

Sources of Support

This study was supported by research grants provided by Siemens Medical Solutions (Malvern, Pa), Bracco Diagnostics (Princeton, NJ), and Medrad (Pittsburgh, Pa). One author (U.J.S.) is a medical consultant to Siemens and Bracco, one (P.C.) is a medical consultant to Bracco, and another (T.G.F.) is an employee of Siemens. The authors who are not employees of or consultants for a company providing support had control of the data and information submitted for publication.

Study Patients

Forty consecutive patients (22 men, 18 women; mean age, 61 years \pm 8 [standard deviation]; age range, 49–73 years) who met our inclusion criteria and who had been referred to the department of cardiology between October 2004 and July 2005 for evaluation of suspected coronary artery disease were prospectively included. The study de-

sign was approved by the Medical University of South Carolina human research committee, and all patients gave written informed consent (after hearing an explanation of radiation risks) for participation in the study and the use of their medical data in compliance with Health Insurance Portability and Accountability Act regulations. Included were only patients in stable condition with regard to symptoms, vital signs, and results of monitored electrocardiography (ECG). Exclusion criteria were (a) unstable symptoms, vital signs, or ECG results; (b) creatinine level of more than 2.0 mg/dL (177 μ mol/L); (c) potential pregnancy; and (d) known allergy to iodinated contrast material (Fig 1). Patients with contraindications to β -blockers (chronic obstructive pulmonary disease, asthma sensitive to β agonists, second- or third-degree heart block, hypotension [$<$ 100 mm Hg systolic blood pressure]) were eligible for participation in the study, but no β -blockers were used in such individuals.

Image Acquisition

CT scanning was performed with a 64-section scanner (Somatom Sensation 64 Cardiac; Siemens, Forchheim, Germany). Scanning parameters were 64 \times 0.6-mm collimation, z-flying focal spot technique (19), 0.33-second rotation time, a pitch of 0.2, 120 kV, and 900 mAs. Patients ($n = 32$) with average heart rates ($>$ 65 beats per minute) received up to two intravenous injections

Advances in Knowledge

- In the presence of heart rates between 80 and 82 beats per minute, two-segment reconstruction algorithms improve image quality at multidetector CT coronary angiography but do not significantly affect overall diagnostic accuracy compared with single-segment reconstruction.
- Significant stenosis ($>$ 50%) can be detected on a per-segment basis with 77.1% sensitivity and 98.6% specificity by using single-segment image reconstruction and with 79.2% sensitivity and 99.1% specificity by using two-segment image reconstruction.

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Abbreviation:

ECG = electrocardiography

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Guarantor of integrity of entire study, U.J.S.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, J.D., C.D.N., T.G.F., T.J.V.; clinical studies, P.L.Z., J.D., C.D.N., T.G.F., T.J.V., P.C.; statistical analysis, S.A.N., T.J.V.; and manuscript editing, P.L.Z., C.D.N., T.J.V., P.C.

See Materials and Methods for pertinent disclosures.

of 5 mg (up to 10 mg total) of metoprolol tartrate (Lopressor; Novartis, East Hanover, NJ) immediately before the examination. A second injection was given if the heart rate did not decrease to below 65 beats per minute after injection of 5 mg of the β -blocker.

Scans were acquired in the cranio-caudal direction with simultaneous recording of the patient's ECG signal to allow image reconstruction on the basis of retrospective ECG gating. The scanning range extended from the midlevel of the ascending aorta to just below the diaphragm. Each patient received 70–90 mL of nonionic contrast medium (iopamidol, 370 mg of iodine per milliliter, Isovue; Bracco) that was power injected (Stellant D; Medrad) through an 18-gauge intravenous antecubital catheter, followed by 50 mL of saline (0.9% sodium chloride) that served as a bolus chaser. The injection rate for both was 5 mL/sec. The amount of contrast medium needed for each examination was individually computed according to the following formula: $V = ST \cdot 5$, where V is volume in milliliters and ST is scanning time in seconds. Bolus timing was achieved by using an automated bolus triggering technique (Care Bolus; Siemens), with a threshold of 160 HU detected within a region of interest (30 mm in diameter) placed on the ascending aorta by one of several technologists. Mean heart rate was 72 beats per minute (range, 61–87 beats per minute) at scan acquisition, mean scanning time was 15.3 seconds (range, 13.2–17.8 seconds), and volume CT dose index was 61.1 mGy. All patients were in sinus rhythm.

Image Reconstruction

Image reconstruction was performed by one of the authors (C.H.) with retrospective ECG gating, a technique that allowed continuous image reconstruction from CT raw data sets during any phase of the cardiac cycle (23,24). Each data set was reconstructed twice—once by using a single-segment and once by using a two-segment adaptive cardiac volume reconstruction algorithm, which are both provided with the standard cardiac software package of the CT

scanner. At single-segment reconstruction, each single transverse section contained data from only one R-R cycle; that is, fan beam data of only one partial rotation (usually 240°–260°) were used, which resulted in a temporal resolution equivalent to half of the rotation time in a centered region of interest (eg, 165 msec for the 0.33-second rotation time) (19,23,25–29). A multidetector spiral interpolation between the projections of adjacent detector rows was used to compensate for table movement and to provide a well-defined section sensitivity profile for images without spiral artifacts.

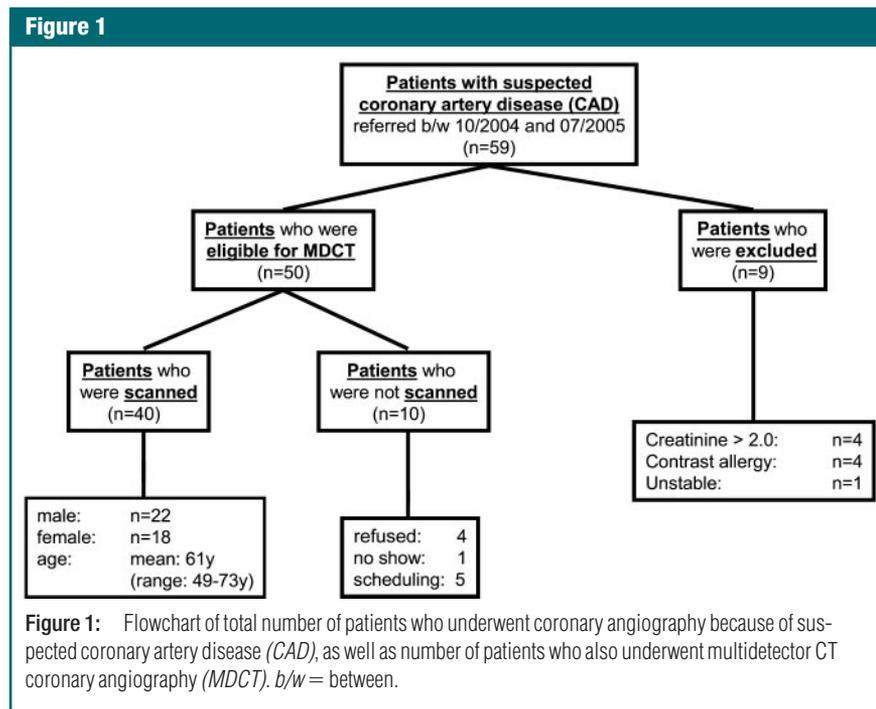
At multisegment reconstruction, temporal resolution is improved by using scanning data from more than one heart cycle for reconstruction of a single transverse image (15,16). With this approach, the partial scanning data set for reconstruction of one image consists of projection sectors from multiple consecutive heart cycles. Depending on the relationship between rotation time and patient heart rate, a temporal resolution between one-half of the rotation time and the rotation time divided by $2M$ is achieved, where M equals the number of projection sectors and the

number of heart cycles used. With the two-segment reconstruction algorithm used in our study, temporal resolution ranges between 165 and 82.5 msec, depending on patient heart rate (Fig 2).

Reconstruction intervals were determined by one of the authors (C.H.) and were relative to the R-R interval (a percentage of the R-R interval defined the midpoint of the reconstruction interval). The intervals of the cardiac cycle with the least cardiac motion were identified by using a preview series that consisted of 0.75-mm transverse sections at the same z-position at the midlevel of the heart, reconstructed at 20 different R-R positions (0%–95% of the R-R interval) in 5% increments. Image reconstruction parameters comprised an individually adapted field of view, a matrix size of 512×512 pixels, a medium soft-tissue convolution kernel (B25f), and a section thickness of 0.75 mm with an increment of 0.3 mm.

Image Analysis

Image evaluation was performed with a three-dimensional-enabled workstation (Leonardo, Siemens) and with a standardized window level of 100 HU and window width of 700 HU. The two re-



constructed data sets (two-segment and single-segment) for each patient were independently analyzed in random order by two cardiovascular radiologists (C.H., U.J.S.), each with 7 years of experience reading cardiac multidetector CT images. The two radiologists were unaware of patient clinical data (coronary angiographic results, any other imaging data, physical examination results, laboratory results, enzyme levels, ECG results, exercise test results, patient history, patient family background). To avoid observer bias, an interval of at least 4 weeks was observed between the analysis of the two-segment data sets and that of the single-segment data sets. However, the 4-week interval was kept only for the purpose of this study, whereas patient care was predicated on results of the reference standard of coronary angiography. Transverse sections, automatically generated curved multiplanar reformations, and thin-slab maximum intensity projections (5 mm) were assessed for image quality and signs of coronary artery stenosis.

Diagnostic accuracy was evaluated on a per-patient and a per-segment (1–15) basis. The latter evaluation was performed according to the classification of the American Heart Association (30). The extent of coronary artery stenosis was classified as follows: no stenosis,

49% or less stenosis, 50%–69% stenosis, 70%–99% stenosis, or total occlusion. On CT scans, the degree of stenosis was measured by using a semiautomated stenosis measuring tool (Circulation; Siemens).

Criteria for the assessment of image quality were the subjective perception of (a) image noise; (b) vessel contrast; (c) sharpness of tissue interfaces; (d) conspicuity of anatomic details; and (e) degree of image degradation by motion, streak, or misregistration artifacts. Each segment was individually analyzed for each of these criteria by using a five-point scale: a score of 1 for unacceptable, 2 for suboptimal, 3 for adequate, 4 for good, and 5 for excellent quality. Sufficient diagnostic quality was when the mean score for a segment was 3 or higher. On the basis of the mean segmental scores, an average image quality score was calculated for each patient.

Reference Standard

All CT findings were compared with findings on corresponding coronary angiograms, which had been obtained by using the Judkin technique. At least four views of the left and two views of the right coronary artery system were analyzed in consensus by three cardiologists (P.L.Z., J.D., C.D.N.), each with more than 5 years (range, 5–9 years) of experience in the interpretation of coronary angiograms and no knowledge of the CT results. Quantitative grading of stenosis on angiograms was performed by using a stenosis-grading tool with automatic distance and scale calibration (Axiom-Artis VA21C; Siemens).

Statistical Analysis

All statistical analyses were performed and graphs were obtained with software (Sample Power 2.0, Sigma Stat 3.0, and Sigma Plot 8.0; SPSS, Chicago, Ill). Categorical variables were presented as percentages, and continuous variables were presented as means \pm standard deviations.

Sample size was estimated on the basis of a two-sided α level ($\alpha = .05$). Power analysis was performed by using a general linear model two-factor analysis of variance, with factor A being im-

age quality at one-segment reconstruction versus image quality at two-segment adaptive cardiac volume reconstruction and factor B being heart rate. A sample size of 40 patients was estimated to provide a power-detecting between-group difference of 94% for factor A, 97% for factor B, and 94% for the interaction between factor A and factor B. The standard deviation of ± 0.9 was used within groups, considering the standard deviation for image quality was ± 0.9 for one-segment reconstruction and ± 0.8 for two-segment adaptive cardiac volume reconstruction. A Cohen convention of large effect size (F) of 0.40 was applied between groups. A P value of .05 or less was considered to indicate a statistically significant difference for all statistical tests.

The agreement between the investigators in the grading of image quality (1–4) was calculated by means of the κ statistic. Results were interpreted as either poor ($\kappa < 0.20$), fair ($\kappa = 0.21$ –0.40), moderate ($\kappa = 0.41$ –0.60), good ($\kappa = 0.61$ –0.80), very good ($\kappa = 0.81$ –0.90), or excellent ($\kappa \geq 0.91$).

The number of coronary segments visible on multidetector CT scans was determined in proportion to the number of segments visualized on coronary angiograms. Any difference between two- and single-segment reconstruction was tested for significance by using a paired t test.

The Wilcoxon signed rank test was used to test the null hypothesis that both reconstruction techniques resulted in similar image quality versus the alternative hypothesis that there was a difference between the methods. A possible effect of the heart rate was assessed by using analysis of variance.

The degree of correlation between multidetector CT and invasive coronary angiography in grading of coronary stenosis was investigated by means of the Spearman correlation. Correlation coefficients for two- and single-segment image reconstruction were compared; a P value of less than .05 was considered to indicate a statistically significant difference.

Accuracy, sensitivity, specificity, and positive and negative predictive values

Figure 2

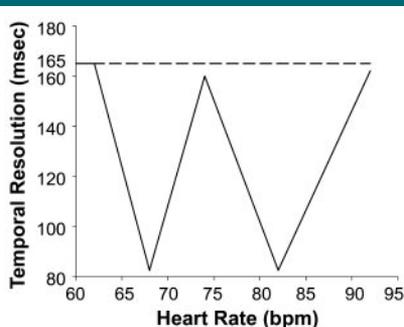


Figure 2: Graph shows temporal resolution at single-segment (dotted line) and two-segment (solid line) image reconstruction relative to patient heart rate. With use of two-segment reconstruction, temporal resolution ranges between 82.5 msec (one-fourth of rotation time) and 165 msec (one-half of rotation time), depending on heart rate.

of multidetector CT for the detection of coronary artery stenosis of more than 50% were determined by using cross tables. Because of data clustering, any differences in this respect between single-segment and two-segment reconstruction for sensitivity and specificity were tested for significance by using generalized estimating equations. Accuracy and positive and negative predictive values are functions of prevalence, so no P value was calculated.

Results

Reader Agreement

The agreement between the two observers for stenosis grading and image quality scores was considered very good and good, with κ values of 0.81 (95% confidence interval: 0.74, 0.89) and 0.78 (95% confidence interval: 0.75, 0.81), respectively. Therefore, all subsequent calculations were performed on the basis of data generated by observer 1 (C.H.).

Segments Visualized

Six hundred coronary artery segments were visible on angiograms, of which 560 (93.3%) were visualized with CT data sets that had been reconstructed by using single-segment image reconstruction and 561 (93.5%) were visualized by using two-segment image reconstruction. In the remaining segments, evaluation was either compromised by misregistration (single-segment reconstruction: four of 40 segments [10%], two-segment reconstruction: four of 39 segments [10%]), motion artifacts (single-segment reconstruction: nine of 40 segments [23%], two-segment reconstruction: eight of 39 segments [21%]), or small vessel diameter (single-segment reconstruction: 27 of 40 segments [68%], two-segment reconstruction: 27 of 39 segments [69%]). The discrepancy in visualization was not significantly different ($P = .35$).

Image Quality

Mean image quality scores were not significantly different ($P = .22$) for single- (3.1 \pm 0.9) and two-segment (3.2 \pm

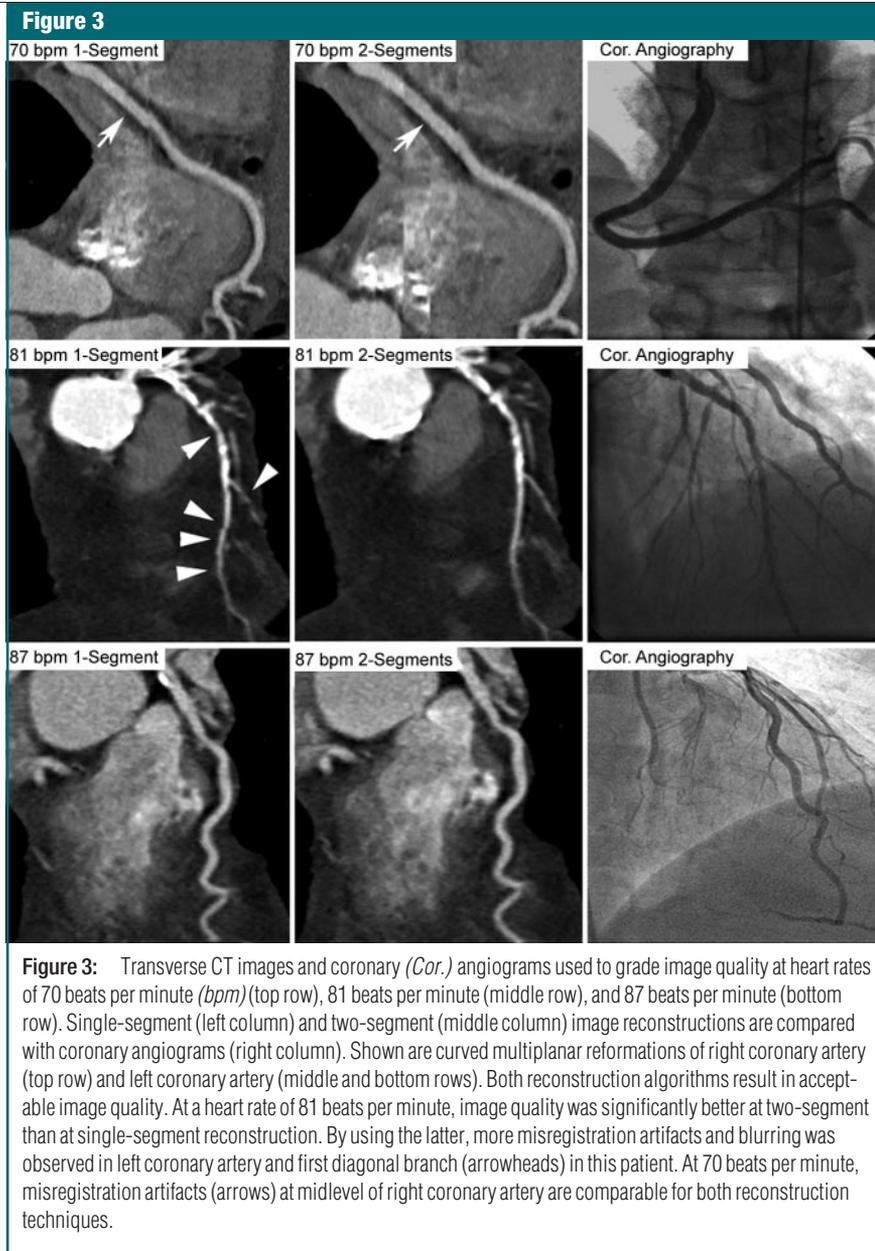


Figure 3: Transverse CT images and coronary (*Cor.*) angiograms used to grade image quality at heart rates of 70 beats per minute (*bpm*) (top row), 81 beats per minute (middle row), and 87 beats per minute (bottom row). Single-segment (left column) and two-segment (middle column) image reconstructions are compared with coronary angiograms (right column). Shown are curved multiplanar reformations of right coronary artery (top row) and left coronary artery (middle and bottom rows). Both reconstruction algorithms result in acceptable image quality. At a heart rate of 81 beats per minute, image quality was significantly better at two-segment than at single-segment reconstruction. By using the latter, more misregistration artifacts and blurring was observed in left coronary artery and first diagonal branch (arrowheads) in this patient. At 70 beats per minute, misregistration artifacts (arrows) at midlevel of right coronary artery are comparable for both reconstruction techniques.

0.8) reconstruction (Fig 3). Irrespective of the reconstruction technique, degraded image quality was found for vessel segments adjacent to the atrioventricular groove (ie, segments 2, 3, 12, 13, and 14) (Table 1). However, the plotting of differences in image quality (ie, quality scores for two-segment reconstruction minus scores for one-segment reconstruction) versus heart rate showed larger differences ($F = 20.358$, $df = 16, 1175$; $P < .001$) at two-segment reconstruction in six (15%) pa-

tients who presented with heart rates of 80–82 beats per minute (Fig 4). At these heart rates, the temporal resolution at two-segment reconstruction is at its optimum at approximately 83 msec, as opposed to 165 msec at single-segment reconstruction, a value that remains stable at all heart rates (Fig 2).

Accuracy

Considering all patients and heart rates, significant coronary artery disease (>50% stenosis) was detected on a per-

segment basis with 77.1% sensitivity (37 of 48 segments) and 98.6% specificity (544 of 552) by using single-segment image reconstruction and with 79.2% sensitivity (38 of 48) and 99.1% specificity (547 of 552) by using two-segment

image reconstruction (Table 2). On a per-patient basis, sensitivity and specificity, respectively, were 100% (16 of 16 patients) and 87.5% (21 of 24) with single-segment image reconstruction and 100% (16 of 16) and 95.8% (23 of 24)

by using two-segment image reconstruction (Table 2). For the comparison of single-segment versus two-segment image reconstruction, the correlation coefficients for sensitivity were 0.941 ($P < .001$) on a per-segment basis and 1.000 ($P < .001$) on a per-patient basis. Correlation coefficients for specificity were 0.800 ($P = .001$) on a per-segment basis and 0.552 ($P < .005$) on a per-patient basis.

In the six patients with heart rates of 80–82 beats per minute, five stenoses greater than 50% were present and were identified on a per-segment basis with 100% sensitivity (five of five) and 94.2% specificity (65 of 69) by using one-segment image reconstruction and 100% sensitivity (five of five) and 98.6% specificity (68 of 69) by using two-segment image reconstruction (Table 2). There was a strong correlation on a per-segment basis for sensitivity ($r = 1.000$, $P = .02$) and specificity ($r = 0.493$, $P < .001$). On a per-patient basis, sensitivity (four of four) and specificity (two of two) were both 100%—irrespective of the reconstruction technique (Table 2).

In total, 11 stenoses greater than 50% were missed with single-segment reconstruction: four due to motion artifacts, five due to small vessel size (<1.5 mm), and two due to heavy calcifica-

Table 1

Image Quality at Single- and Two-Segment Image Reconstruction on a Per-Segment Basis at 64-Section CT Angiography

Coronary Artery	Coronary Segment	Image Reconstruction Algorithm	
		Single Segment	Two Segment
Right coronary artery	1	3.1 ± 0.9	3.3 ± 0.7
	2	2.8 ± 0.9	3.0 ± 0.8
	3	2.9 ± 0.9	3.1 ± 0.8
	4	3.2 ± 0.8	3.3 ± 0.8
Left coronary artery	5	3.4 ± 0.8	3.5 ± 0.7
	6	3.3 ± 0.7	3.4 ± 0.7
	7	3.2 ± 0.7	3.3 ± 0.7
	8	3.1 ± 0.9	3.2 ± 0.8
	9	3.1 ± 0.9	3.2 ± 0.8
	10	3.1 ± 0.8	3.2 ± 0.8
Left circumflex coronary artery	11	3.2 ± 0.7	3.3 ± 0.7
	12	2.8 ± 1.0	2.9 ± 0.9
	13	2.7 ± 1.1	2.9 ± 1.1
	14	2.9 ± 1.2	2.9 ± 1.2
	15	3.1 ± 1.1	3.1 ± 1.1
Mean	1–15	3.1 ± 0.9	3.2 ± 0.8

Note.—Data are means ± standard deviations.

Figure 4

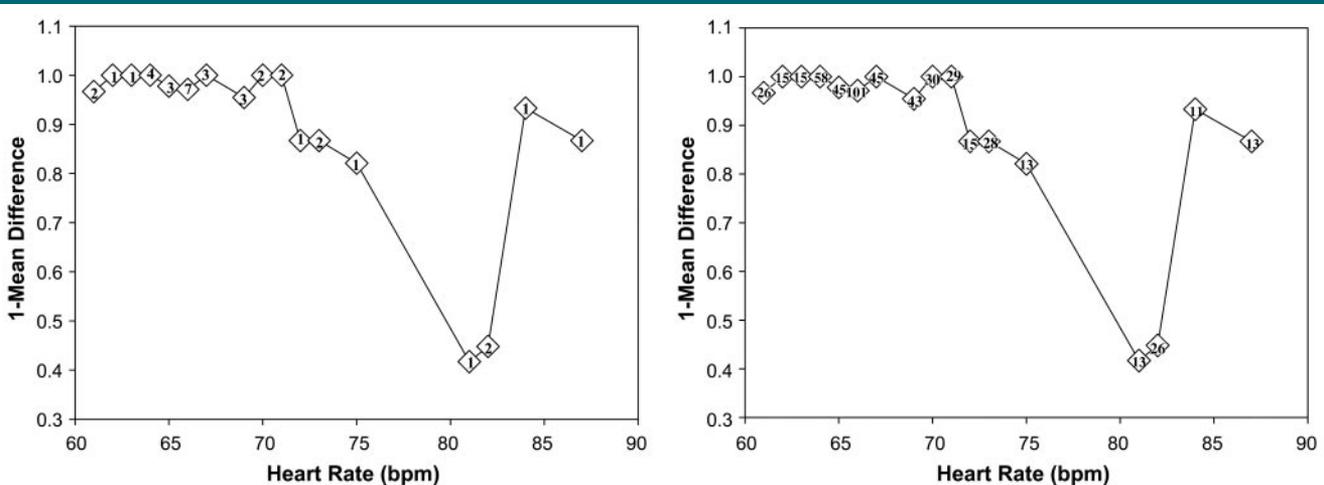


Figure 4: Graphs of mean differences in image quality versus heart rate show significantly ($P = .03$) better image quality for two-segment reconstruction at heart rates of 80–82 beats per minute (*bpm*). At these heart rates, temporal resolution of two-segment reconstruction is at its optimum at approximately 83 msec. Left: Graph shows results on per-patient basis. Right: Graph shows results on per-segment basis. Values in diamonds indicate number of patients (left) and segments (right).

tions. Ten stenoses were missed with two-segment image reconstruction: three due to motion artifacts, five due to small vessel size, and two due to heavy calcifications.

For grading of coronary artery stenosis, correlation coefficients were 0.64 for single-segment image reconstruction and 0.66 for two-segment reconstruction. There were no significant differences ($P = .43$).

Discussion

According to the results of this study, the improved temporal resolution of two-segment image reconstruction translates into better image quality at 64-section coronary CT angiography at certain heart rates but does not improve overall diagnostic accuracy in a clinical population with a broad variety of heart rates. In our consecutive cohort of 40 patients with a relatively wide range of clinically relevant heart rates, similarly high image quality and diagnostic accuracy were observed for both reconstruction strategies. The influence of the improved temporal resolution of multisegment reconstruction on the accuracy of stenosis detection at coronary CT angiography had not been previously investigated, to our knowledge.

Our findings on improvements in image quality for certain heart rates at 64-section coronary CT angiography with two-segment reconstruction correspond reasonably well to the results of previous studies with four- to 12-section CT scanners (15,22,27). Kachelriess et al (15) showed that two-segment reconstruction for heart rates greater than 70 beats per minute yielded better results than single-segment reconstruction when the table feed was restricted. In a small group of 10 patients, Flohr and Ohnesorge (27) demonstrated improvements in image quality by using two-segment reconstruction compared with single-segment reconstruction with four-section CT and a 500-msec gantry rotation time. Halliburton et al (22) showed a beneficial effect of segmented image reconstruction in the clinically relevant heart rate range of 74–90 beats per minute by using 12-section CT and a

Table 2

Diagnostic Accuracy of Single- and Two-Segment Image Reconstruction at 64-Section CT Angiography for Grading Stenoses

Diagnostic Accuracy Measurements according to Heart Rate	Single-Segment Reconstruction	Two-Segment Reconstruction
Per-segment basis		
61–87 beats per minute ($n = 600$)		
Accuracy	96.7 (94.4, 97.2) [580/600]	97.5 (95.9, 98.6) [585/600]
Sensitivity	77.1 (62.6, 87.9) [37/48]	79.2 (65.0, 89.5) [38/48]
Specificity	98.6 (96.3, 99.3) [544/552]	99.1 (97.9, 99.7) [547/552]
Positive predictive value	80.4 (66.1, 90.6) [37/46]	88.4 (74.9, 96.1) [38/43]
Negative predictive value	98.0 (96.5, 97.9) [543/554]	98.2 (96.7, 99.1) [547/557]
80–82 beats per minute* ($n = 74$)		
Accuracy	94.6 (86.7, 98.5) [70/74]	98.7 (92.7, 99.9) [73/74]
Sensitivity	100 (47.8, 100) [5/5]	100 (47.8, 100) [5/5]
Specificity	94.2 (85.8, 98.4) [65/69]	98.6 (92.2, 99.9) [68/69]
Positive predictive value	55.6 (21.2, 86.3) [5/9]	83.3 (35.9, 99.6) [5/6]
Negative predictive value	100 (94.5, 100) [65/65]	100 (94.7, 100) [68/68]
Per-patient basis		
61–87 beats per minute ($n = 40$)		
Accuracy	92.5 (79.6, 98.4) [37/40]	97.5 (86.8, 99.9) [39/40]
Sensitivity	100 (79.4, 100) [16/16]	100 (79.4, 100) [16/16]
Specificity	87.5 (67.6, 97.3) [21/24]	95.8 (78.9, 99.9) [23/24]
Positive predictive value	84.2 (60.2, 96.6) [16/19]	94.1 (71.3, 99.8) [16/17]
Negative predictive value	100 (83.9, 100) [21/21]	100 (85.2, 100) [23/23]
80–82 beats per minute* ($n = 6$)		
Accuracy	100 (54.1, 100) [6/6]	100 (54.1, 100) [6/6]
Sensitivity	100 (39.8, 100) [4/4]	100 (39.8, 100) [4/4]
Specificity	100 (15.8, 100) [2/2]	100 (15.8, 100) [2/2]
Positive predictive value	100 (39.8, 100) [4/4]	100 (39.8, 100) [4/4]
Negative predictive value	100 (15.8, 100) [2/2]	100 (15.8, 100) [2/2]

Note.—Data are percentages, with 95% confidence intervals in parentheses and numbers used to calculate percentages in brackets.

* Heart rates where image quality was significantly better for two-segment reconstruction.

420-msec gantry rotation time. However, this was different from Flohr and Ohnesorge's results (27), in which quality scores were not significantly different for single- versus two-segment reconstruction when four-section CT and a 500-msec gantry rotation time were used (22). The authors (22) conclude that at four-section CT, the benefits of better temporal resolution with two-segment image reconstruction are not able to offset the limitations incurred by the broadening of the section sensitivity profile, broadening of the time sensitivity profile, and the dynamic definition of temporal resolution according to heart rate.

Broadening of the section sensitivity profile leads to spatial blurring of the image, depending on the reconstruction

position relative to the detector position (15,27). With two-segment reconstruction at four-section CT, interpolation of data acquired at a long distance from the desired position must be performed because of the inadequately high table feeds required to cover the heart within a reasonable breath-hold time (22,24, 27,28). At 12-section CT, increased coverage per rotation allows the reduction of the spiral pitch so that less interpolation is required (22). Because of increased volume coverage per rotation, this effect is even more pronounced at 64-section CT (19).

With multisegment image reconstruction algorithms, diagnostic accuracy may be affected by broadening of the time sensitivity profile because of inconsistencies of subsequent heart cy-

cles. It cannot be assumed that the heart follows the exact motion pattern with every beat, so spatial inconsistencies and blurring occur if data for a single transverse image are sampled from several heartbeats. In addition, segmented reconstruction algorithms assume periodicity of consecutive cardiac cycles. However, data from several subsequent cardiac cycles with slightly different R-R interval lengths will be derived from slightly different cardiac phases (22). At single-segment image reconstruction, this timing shift causes a typical stair-step appearance of subsequent transverse images, best visualized on three-dimensional reformations along the z-axis. At multisegment reconstruction, this timing shift is averaged out during reconstruction of each transverse image, which reduces the stair-step artifacts on reformations but increases blurring within individual images. Theoretically, such spatial inconsistencies impair diagnostic accuracy for stenosis detection and grading. This, however, was not observed in our patient population, likely because of improved temporal resolution at 64-section CT as compared with previous scanner generations used in other studies (15,22,27).

Segmented reconstruction algorithms involve dynamic definition of temporal resolution as a function of the heart rate, which, particularly in patients with irregular heart rates, may contribute to impaired image quality (22). By using two-segment reconstruction, temporal resolution oscillates between one-half and one-fourth of the gantry rotation, depending on the heart rate (24,27,28). This effect likely impairs image quality at four-section CT (22) but evidently had no significant effect at 64-section CT. Better temporal resolution due to faster gantry rotation decreases the absolute difference between the effective temporal resolution of segmented and that of nonsegmented image reconstruction; the decreased difference may benefit image quality by decreasing oscillation between the extremes of temporal resolution with irregular heart rates.

Significantly better image quality was observed for segmented image re-

construction at heart rates of 80–82 beats per minute, in which temporal resolution is at its optimum of approximately 83 msec. At these heart rates, the gain in temporal resolution thus may outweigh any impairment of image quality due to broadened time sensitivity profiles or dynamic definition of temporal resolution.

Our study had limitations. Only nine patients with heart rates in the range of 75–87 beats per minute, in which the gains in temporal resolution by using two-segment reconstruction are the most pronounced, were included. However, power analysis revealed a 96.6% power to detect a 0.5-point difference with 95% confidence. Only two-segment reconstruction was addressed, which was specific for the scanner investigated, but does not represent the reconstruction standard of other scanners that offer up to six-segment reconstruction algorithms. However, use of an increasing number of segments results in increased oscillation between minimum and maximum temporal resolution (17). From a technical and physiologic point of view, the benefit of using an increasing number of segments for image reconstruction thus appears questionable but should be investigated in future studies.

Several groups (11–14,31) have demonstrated that the choice of reconstruction timing substantially affects the presence of cardiac motion artifacts and thus may be more relevant for CT coronary angiography than the choice of reconstruction algorithm. We tried to compensate for this by selecting optimal reconstruction intervals from a preview series consisting of 20 single-section reconstructions at different phases of the cardiac cycle and by comparing only single- and two-segment data sets that were reconstructed during the same cardiac phase.

Although segmented image reconstruction might help to reduce cardiac motion artifacts at 64-section CT coronary angiography with a 330-msec gantry rotation time, optimal image quality still is consistently achieved only in patients with low heart rates. The use of a β -blocker for heart rate control prior to scanning thus is highly recommended

(32). In addition, at low heart rates, not only is image quality improved but patient radiation exposure is also significantly reduced when ECG-gated tube current modulation (ECG pulsing) (32, 33) is used. ECG-gated tube current modulation is effective only in patients with slow and steady heart rates, in whom the optimal time point for image reconstruction predictably occurs during mid-diastole. ECG-gated tube current modulation increasingly loses its efficacy at faster heart rates, because the period of reduced tube output becomes progressively shorter relative to the cardiac cycle (32,33).

In conclusion, use of two-segment image reconstruction at 64-section CT coronary angiography overall results in equal diagnostic accuracy and similar image quality compared with those at single-segment reconstruction; at a heart rate as high as 97–82 beats per minute, image quality is significantly higher at two-segment reconstruction, so routine use of segmented reconstruction algorithms in patients with arrhythmia or tachycardia appears recommendable.

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