Coronary Artery Disease

Image Quality of 256-Slice Computed Tomography for Coronary Angiography

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Purpose: To assess the image quality of 256-slice computed tomographic angiography (CTA) and to identify possible impact factors associated with image quality.

Methods: From November 2009 to January 2010, 506 patients underwent 256-slice CTA at our institute. A total of 451 patients were enrolled in our study, after 55 patients were excluded because of prior bypass surgery and stenting. CTA image quality was graded by two observers using a 4-point scale: excellent (score 1), good (score 2), moderate (score 3), poor and non-diagnostic (score 4). The coronary arteries were divided into 15 segments. Image quality was correlated to the subjects' age, gender, body mass index, heart rate, and calcium scores.

Results: We evaluated 6650 coronary segments from CTA images of our enrolled 451 patients. The mean image quality score of all coronary segments was 1.14. Most coronary segments (99.7%) were assessable, and only 21 segments (0.3%) were non-diagnostic. A total of 5824 coronary segments were classified as having excellent image quality. Forty-two patients (9.3%) required control of heart rate with beta-blockers before CTA could be performed. Male patients had better image quality than female patients. Heart rate and severity of calcification were impact factors associated with image quality.

Conclusions: Examination with 256-slice CTA provides good image quality and can effectively evaluate most coronary segments.

Key Words: Coronary angiography • Heart rate • Image quality • Multi-slice computed tomography

INTRODUCTION

Noninvasive coronary angiography has become increasingly popular in recent years due to advances in multi-slice computed tomography (MSCT). MSCT has the advantages of faster gantry rotation times, increased X-ray tube power, and larger detector coverage. Therefore, MSCT provides a shorter scanning time, better image quality, and lower radiation dose. Several studies have investigated the diagnostic performance of MSCT and shown that MSCT has a high negative predictive value and a high assessable rate of coronary segments.[1-6] These properties make MSCT a reliable tool to exclude coronary artery disease in patients at intermediate risk. While clinical application of other imaging modalities such as tissue Doppler parameters[7] and intravascular ultrasound[8] continue to be useful in evaluating coronary artery disease, conventional angiography with its invasiveness and risks has been superseded by noninvasive 64-slice and the newer, wider 256-slice MSCT.[9]

However, results of noninvasive coronary angiography using 64-slice computed tomography (CT) are limited by heavy coronary calcifications, arrhythmias, and faster heart rates. These limitations may cause artifacts and degrade the quality of CT images. New generation MSCT scanners have a faster gantry rotation time with multi-segment reconstruction algorithms that can

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overcome the artifacts caused by arrhythmias and faster heart rates, thereby avoiding the use of beta-blockers to slow the heart rate. Despite these technological advances, heavy coronary calcification remains an unresolved problem, and blooming and partial volume artifacts interfere with the interpretation of coronary segments. A study of the performance of a 64-slice vs. a 256-slice CT coronary angiography in two similar populations demonstrated that the 256-slice CT had superior diagnostic performance in detecting obstructive coronary artery disease; however, CTCA performance was definitely affected in severely calcified or stented segments.[9]

Several studies have evaluated the image quality of MSCT, including studies of the image quality of 256-slice CT using prospectively or retrospectively ECG-gated techniques. Law et al. applied retrospective gating vs. prospective triggering for noninvasive coronary angiography using 256-slice CT with 270 ms gantry rotation. The authors achieved more than 50% favorable image scores in 252 patients, with no significant differences between prospective vs. retrospective gating techniques.[10] Jeong et al. compared image quality and radiation doses of 128-slice multidetector CT using step-and-shoot prospectively-gated method vs. retrospectively-gated in 160 patients. Consistent quality was achieved in coronary artery segments and the step-and-shoot method allowed a lower radiation dose, although patients with higher body mass index required larger radiation doses.[11] Similarly, Hou et al. compared image quality and radiation dosage with prospective vs. retrospective ECG-gated 256-slice CT with the goal of obtaining an upper-limit heart rate necessary to achieve reliable diagnostic image quality. In that study of 200 patients, prospectively-gated 256-slice CT enabled a significant reduction in radiation dose and provided similar image quality to the retrospectively-gated methods. The authors also noted that the technique was applicable across a wider range of heart rates (i.e., up to 75 bpm) than previously demonstrated.[12]

Although the above studies analyzed technical equipment-related aspects of image quality and the upper limit of heart rate associated with good image quality, no large scale studies have investigated the possible effects of patient characteristics such as age, gender, or calcification on the image quality of a 256-slice CT. The aim of this study was to evaluate the image quality of non-invasive coronary angiography using 256-slice CT in patients with suspected coronary artery disease (CAD).

METHODS

Study population

From November 2009 to January 2010, 506 individuals underwent CTA at our institute. Fifty-five subjects were excluded because of implanted coronary stents or prior bypass surgery, and 451 subjects were finally enrolled in this study. The study protocol was approved by the local institutional review board, and all patients provided signed informed consent.

Protocol for 256-slice CTA evaluation

All patients underwent two CT tests (calcium scoring and angiography) using a Brilliance iCT 256-slice CT scanner (Philips, Eindhoven, The Netherlands). Beta-blockers with propranolol (40 mg) were prescribed orally if the heart rate was more than 90 bpm prior to CTA, and sublingual nitroglycerin was prescribed routinely if there were no contraindications. All patients, regardless of heart rates, were imaged with retrospective ECG-gated acquisitions. Scanning was conducted in a cranio-caudal direction covering a region approximately 1 cm caudal to the tracheal bifurcation to the level of the diaphragm. The scanning delay was determined using an automatic bolus tracking technique. A single unenhanced scan was obtained at the level of the aortic root, and this scan was used to place a 10-mm diameter circular region of interest inside the lumen of the ascending aorta. Nonionic contrast medium (Optiray 350, Tyco Healthcare, Montreal, Quebec, Canada) was then injected based on patient weight (1 mL/kg) and heart rate (5 mL less for heart rate < 60 bpm, and 5 mL more for heart rate > 80 bpm) at a flow rate of 5 mL/second, followed by a 25-mL bolus of saline at the same rate using a dual-head injector (Optivantage, Mallinckrodt, Taco Healthcare, Montreal, Quebec, Canada). A mean of about 16 seconds (range 11-23 seconds) after the intensity (density of calcification) in the region of interest exceeded 110 Hounsfield units, inspiratory breath-hold scanning was initiated. The 256-

slice scanner incorporated real-time arrhythmia management capability that enabled the x-ray acquisition to be paused on the detection of ectopy during a prospective ECG-gated scan and resumed at the same axial location once normal sinus rhythm had returned.

The images were reconstructed with a slice thickness of 0.9 mm, a reconstruction increment of 0.5 mm, and a medium soft-tissue convolution kernel. The reconstructed matrix size was 512 × 512. The field of view was manually adjusted to encompass the heart. All images were transferred to a separate workstation equipped with post-processing software (Extended Brilliance Workspace 4.0, Philips).

For retrospective ECG-gated acquisitions, the following parameters were used: 128 × 0.625 mm detector collimation, 256 × 0.625 mm slice collimation by means of a dynamic z-focal spot for double sampling, and 270 ms gantry rotation time. Applying the common half-scan reconstruction technique allowed for a minimum temporal resolution of up to 135 ms. Heart rate-dependent pitch was set at 0.16 for patients with a heart rate of 62 bpm or less, and 0.18 for patients with a heart rate of more than 62 bpm. The tube voltage was 120 kV and an effective tube current of between 471 mA and 860 mAs was applied according to patient weight. To produce the best possible image quality with the retrospective technique, ECG-based tube current modulation was turned off for all patients.

Calcium scoring was done using the Agatston calcium scoring method. Calcium scores are calculated using a weighted value assigned to the highest density of calcification in a given coronary artery. The density is measured in Hounsfield units with a score of 1 for 130-199 HU (no calcification or small calcification located outside lumen); 2 for 200-299 HU (calcification occupies < 50% lumen); 3 for 300-399 HU (calcification occupies > 50% lumen) and 4 for 400 HU and greater (calcification occupies the whole lumen). The weighted score is then multiplied by the area in square millimeters of the coronary calcification.

Radiation dose

The radiation dose was determined using the volume CT dose index ($CTDI_{vol}$) in Gy, as provided on the scanner console, and the effective dose was expressed in mSv. The dose-length product (DLP) was defined as the volume CT dose index multiplied by scan length (cm), and was an indicator of the integrated radiation dose of an entire CT examination. An approximation of the effective dose was obtained by multiplying the DLP by a conversion factor, k (= 0.017 $mSv/mGy^{-1}/cm^{-1}$).

Image analysis

Coronary arteries were divided into 15 segments using the American Heart Association 15-segment model.[13] All CT images were interpreted by two independent cardiovascular radiologists, each with more than 5 years experience in cardiac CT imaging. For each segment, the interpreter gave a subjective score for coronary image quality as follows: 1. excellent (absence of artifacts related to motion or coronary calcification); 2. good (minor artifacts); 3. moderate (considerable artifacts but maintained visualization of the arterial lumen); and 4. poor (non-diagnostic because of severe motion artifacts or severe coronary calcification) (Figure 1). Images with scores from 1 to 3 were defined as

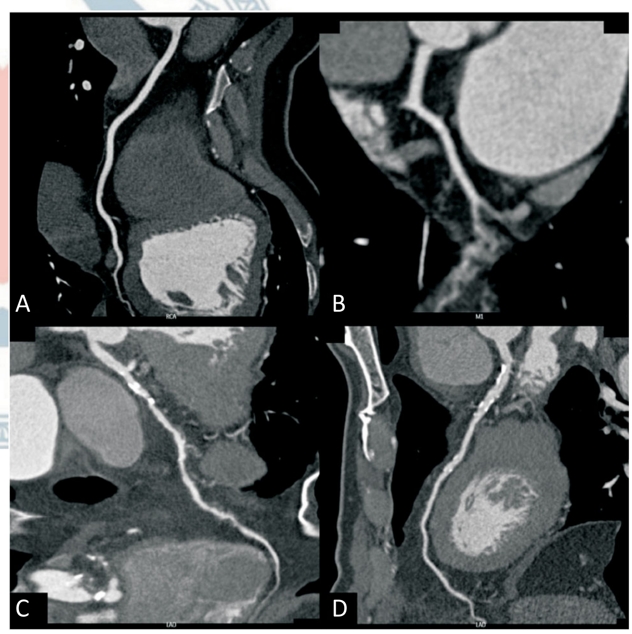

Figure 1. *(A) Excellent image quality of the right coronary artery, score 1. (B) Severe motion artifact of the marginal branch of the left circumflex artery, score 4. (C) Several calcifications located at the proximal portion of the left anterior descending artery, occupying the vessel lumen and interfering with the interpretation of that segment. (D) Small but diffuse calcifications with acceptable image quality. * Coronary calcium scoring includes: score 1, no calcification or small calcification located outside lumen; score 2, calcification occupies < 50% lumen; score 3, calcification occupies > 50% lumen; score 4: calcification occupies whole lumen.*

assessable image quality, and all inter-reader visual differences were resolved by a third observer.

Statistical analysis

Continuous variables were expressed as median and range, and the categorical variable (gender) was expressed as count with percentage. Simple and multiple linear regression models were used to identify the impact factors associated with image quality, and summarized by the weight coefficient (β) with the corresponding 95% confidence interval (CI). The variables with p values less than 0.1 in the simple linear regression models were stepwise selected into the multiple linear regression model. Statistical significance was set at 0.05, and statistical analyses were performed using SPSS 15.0 statistics software (SPSS Inc, Chicago, IL, USA).

RESULTS

Of the 451 subjects enrolled in this study, there were 310 males and 141 females; the mean age was 56.5 ± 10.1 years (median 56, range 28-82 years), and all patients were evaluated with the retrospective gating method. Forty-two (9.3%) subjects required administration of beta-blockers to slow their heart rate before CTA. The baseline characteristics of the patients are shown in Table 1.

Table 1. Baseline characteristics of the 451 patients

Characteristics	Value
Male sex – no. (%)	310 (68.7)
Age (median/range) – yr	56 (28-82)
Body mass index – kg/m^2	
Median	25.2
< 19 – no. (%)	9 (2.0)
19-30 – no. (%)	395 (87.6)
> 30 – no. (%)	47 (10.4)
Beta-blockers required before CTA – no. (%)	42 (9.3)
Heart rate on CTA (median/range)	65 (41-130)
Agatston calcium score – no. (%)	
0	215 (47.7)
> 0-10	26 (5.8)
> 10-100	91 (20.2)
> 100-400	73 (16.2)
> 400	46 (10.2)
Radiation dose (median/range)	16.6 (10.0-27.0)

A total of 6650 coronary segments were included in this study. Most segments (6629/6650, 99.7%) were assessable, and 87.6% (5824/6650) were classified as having excellent image quality (score 1) on CTA based on the definitions applied in this study. Only 21 segments (0.3%) were non-diagnostic (score 4); 12 were caused by heavy calcification and 9 were caused by motion artifacts (Table 2). The mean image quality score of all segments was 1.14, and the mean image quality scores of each coronary artery are summarized in Table 2. Two hundred and nineteen segments required a third reader because of inter-reader visual differences. The inter-reader variability was 3.3%. The median effective radiation dose was 16.6 mSv (range, 10.0~27 mSv).

Age, gender, heart rate, and calcium scores all had p values of less than 0.1 in simple linear regression analysis, and were possible independent impact factors associated with image quality. Age was excluded from the multiple linear regression model through model selection by the stepwise method, and thus gender, heart rate, and calcium score were the independent impact

Table 2. Image quality of 256-slice computed tomographic coronary angiography by different coronary artery segments

	Image quality				
	1	2	3	4	Mean
RCA-P	417 (92.5%)	29 (6.4%)	3 (0.7%)	2 (0.4%)	1.09
RCA-M	399 (88.5%)	47 (10.4%)	4 (0.9%)	1 (0.2%)	1.13
RCA-D	430 (95.3%)	18 (4.0%)	2 (0.4%)	1 (0.2%)	1.06
PD	413 (92.0%)	34 (7.6%)	2 (0.4%)	0	1.08
LM	446 (98.9%)	4 (0.9%)	1 (0.2%)	0	1.01
LAD-P	401 (88.9%)	35 (7.8%)	11 (2.4%)	4 (0.9%)	1.15
LAD-M	419 (92.9%)	27 (6.0%)	4 (0.9%)	1 (0.2%)	1.08
LAD-D	416 (92.2%)	35 (7.8%)	0	0	1.08
D1	317 (70.3%)	125 (27.7%)	6 (1.3%)	3 (0.7%)	1.32
D2	289 (76.3%)	79 (20.8%)	9 (2.4%)	2 (0.5%)	1.27
LCX-P	434 (96.2%)	15 (3.3%)	2 (0.4%)	0	1.04
LCX-D	411 (91.1%)	37 (8.2%)	2 (0.4%)	1 (0.2%)	1.10
OM	292 (68.9%)	125 (29.5%)	5 (1.2%)	2 (0.5%)	1.33
PL	383 (86.5%)	55 (12.4%)	3 (0.7%)	2 (0.5%)	1.15
PD	357 (80.2%)	81 (18.2%)	5 (1.1%)	2 (0.4%)	1.22

D, distal; D1, first diagonal; D2, second diagonal; LAD, left anterior descending artery; LCX, left circumflex artery; LM, left main coronary artery; M, mid; OM, obtuse marginal; P, proximal; PD, posterior descending; PL, posterolateral; RCA, right coronary artery.

factors in the multiple linear regression model. After controlling the heart rate and calcium scores, male subjects had a relatively better image quality than females (β = -0.0452, p = 0.005); the image quality was decreased by 0.0035 for each unit increase in heart rate; the Pearson correlation coefficient was 0.261, indicating a weak linear correlation between heart rate and image quality ($p < 0.001$). Subjects with calcium scores of > 100-400 (β = 0.0431, p = 0.038) and > 400 (β = 0.2108, p < 0.001) had worse image quality than those with a calcium score of 0. The image quality decreased slightly with increasing body mass; however, this was not statistically significant (Table 3).

DISCUSSION

Our results showed that 256-slice CTA provides comparatively good image quality as defined in this study and freedom from motion artifacts in most coronary segments. A trend of decreased image quality was noted in association with older age, faster heart rate, and higher calcium score. Overall, male patients had better image quality than female patients. Additionally, body mass seemed to be an impact factor associated with image quality, however no statistical significance was found.

A possible explanation for why young and male patients had a better image quality is that these patients may have been able to hold their breath better and longer than older and/or female patients. However, this is only a postulated explanation and cannot be proven in this retrospective evaluation, which did not include appropriate data. A previous study investigating the effect of gender on maximal breath-hold time found that there were no outstanding differences in breath-holding ability between men and women who were apnea-free.[14] However, to our knowledge, no data are available on the influence of age on breath-hold ability.

Overweight status was a factor affecting image quality, although it was a non-significant association in our study. We have found that one way to overcome the signal attenuation by a fat layer is to increase the tube current with increasing body mass index.

A rapid heart rate may cause motion and stair-step artifacts and decrease image quality.[13] However, beta-blockers were not routinely used to slow the heart rate in our study. Although the overall image quality score was good, heart rate still had a significant effect on image quality. Heart rate variability has also been reported to be a contributor to suboptimal image quality, although its influence is controversial with different studies showing conflicting results.[15-18] We did not evaluate heart rate variability in the current study. Clinically, arrhythmia definitely interferes with the image quality of CTA in some patients. In our experience, frequent premature beats may cause motion and stair-step artifacts in prospective ECG-gated acquisition, and

Table 3. Summary of the impact factors on the mean image quality by simple and multiple linear regression models

		Simple linear regression model		Multiple linear regression model	
		β (95% CI)	p value	β (95% CI)	p value
Age (year)		0.0023 (0.0008, 0.0038)	0.004*		
Gender	Male	-0.0331 (-0.0667, 0.0005)	0.05	-0.0452 (-0.0767, -0.0138)	0.005*
	Female	Reference		Reference	
BMI (kg/m^2)	< 19	Reference			
	19-30	0.0320 (-0.0802, 0.1442)	0.58		
	> 30	0.0385 (-0.0826, 0.1595)	0.53		
Heart rate		0.0041 (0.0027, 0.0055)	< 0.001*	0.0035 (0.0022, 0.0049)	< 0.001*
Calcium score	0	Reference		Reference	
	> 0-10	-0.0303 (-0.0943, 0.0337)	0.35	-0.0393 (-0.1008, 0.0223)	0.21
	> 10-100	-0.0261 (-0.0647, 0.0124)	0.18	-0.0137 (-0.0510, 0.0236)	0.47
	> 100-400	0.0291 (-0.0127, 0.0708)	0.17	0.0431 (0.0023, 0.0839)	0.04*
	> 400	0.2024 (0.1523, 0.2524)	< 0.001*	0.2108 (0.1617, 0.2599)	< 0.001*
Radiation dose		-0.0016 (-0.0074, 0.0041)	0.58		

* Indicates a significant influence on image quality.

antiarrhythmic agents should be prescribed to suppress arrhythmias to improve the image quality. Some patients experience tachycardia or premature beats because of the discomfort caused by bolus injections of contrast medium such as pain or a burning sensation. In such cases, premedication with beta-blockers may be helpful and may ultimately improve image quality.

Twenty-one coronary segments could not be evaluated in this study. Twelve segments were non-diagnostic because of heavy calcification and 9 because of motion artifacts occurring at the side branches and the distal portion of the coronary arteries. Heavy calcification remains an unresolved problem in CTA. Evaluation with 256-slice CTA is recognized for its highly reproducible quantification of stenotic narrowing and atherosclerotic plaque, and as such can be useful in improving assessment of CAD risk in symptomatic patients.[6] However, observer agreement is needed, which may be more difficult to achieve in asymptomatic patients. In the present study, only 26.4% of our study population had a coronary calcium score greater than 100, suggesting that our study population may be relatively low-risk. Small and diffuse calcifications may not influence the interpretation of coronary segments despite a high total calcium score. However, large calcifications may obscure the visualization of coronary segments and increase the occurrence of the blooming effect and partial volume artifacts, thereby decreasing the diagnostic accuracy and reducing the image quality (Figure 1). Accordingly, the most significant factors are the distribution and size of the calcifications rather than the total calcium score.

In this study, according to the observations of two radiologists using the definitions established in methods above, the excellent or good image quality rate was 98.8%, and the non-diagnostic rate was 0.3%. These results are similar to studies using 256-, 320-slice CT and dual source CT, and better than those for 64- and 128-slice CT.[19-24]

Exposure to radiation is a major concern with the use of MSCT. The mean effective dose in this study was 16.6 mSv, which is relatively high. Because subjects were selected during the early phase of our learning curve, most were scanned with retrospective ECG-gated acquisition to overcome the interference of cardiac dysrhythmias, even if the patient's heart rate was under 70 bpm, thereby enhancing the radiation dose.

LIMITATIONS

The present study has limitations. This is a single center study with no head-to-head comparisons with other CT scanners (64-slice, 320-slice, or dual source CT), which limits the interpretation of our results. The lack of a control group precludes establishing specific parameters for image quality, and our observed results are based on definitions established for this study. Additional case-control study is needed to confirm our results. Also, image quality scoring was subjective and thus susceptible to observer bias. We did not evaluate the influence of prospective and retrospective ECG-gated acquisitions. However, we did not find any significant differences in image quality between prospective and retrospective ECG-gated acquisitions reported in previous studies.[10,25] With regard to image quality, we only evaluated the presence of motion artifacts and calcifications. Other image quality indices, such as signal-to-noise ratio and heart rate variability were not evaluated in this study. Only 26.4% of patients in the present study had calcium scores over 100 and they were at relatively lower risk for CAD compared with the general population. In addition, patients who had undergone stenting and bypass surgery were excluded from this study. Such patients may have more metallic artifacts and calcifications thereby decreasing the image quality of CTA.

CONCLUSIONS

According to the subjective observations of two radiologists using comparative definitions established for this study, 256-slice CTA provided excellent image quality in most coronary segments with only a few non-diagnostic segments caused by motion artifacts and calcifications. A trend of decreased image quality was noted associated with increasing age, faster heart rate, higher calcium scores, and female gender. Our results indicate that routine use of beta-blockers administered prior to imaging exams with 256-slice CT may help to achieve better image quality.

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