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Impact of beta-blockade premedication on image quality of ECG-gated thoracic aorta CT angiography

Pegah Entezari, Jeremy Collins, Hamid Chalian, Huseyin Gurkan Tore, James Carr and Vahid Yaghmai

Abstract

Background: Thoracic aortic aneurysm is one of the most common aorta pathologies worldwide, which is commonly evaluated by computed tomography angiography (CTA). One of the routine methods to improve the image quality of CTA is heart rate reduction prior to study by beta-blockade administration.

Purpose: To assess the effect of beta-blockade on image quality of the ascending aorta in electrocardiography (ECG)-gated dual-source CTA (DSCTA) images.

Material and Methods: In this retrospective study, ECG-gated thoracic aorta CTA images of 40 patients without beta-blocker administration were compared with ECG-gated images of 40 patients with beta-blockade. Images of the aorta were analyzed objectively and subjectively at three levels: sinus of Valsalva (sinus), sinotubular junction (STJ), and mid ascending aorta (MAA). Quantitative sharpness index (SI) and signal-to-noise ratio (SNR) were calculated and two radiologists evaluated the image quality using a 3-point scale.

Results: Mean heart rate in beta-blocker and non-beta-blocker groups was 61.7 beats per minute (bpm) (range, 58.1–63.9 bpm) and 72.9 bpm (range, 69.3–84.1 bpm), respectively ($P < 0.05$). Aorta wall SI, SNR, and subjective grading were comparable between the two groups at all three levels ($P > 0.05$).

Conclusion: Beta-blocker premedication may not be necessary for imaging of ascending aorta with ECG-gated DSCTA.

Keywords

Computed tomography angiography, beta-antagonist, heart rate, ascending aorta, image quality

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Introduction

Aortic disease is responsible for approximately 45,000 annual deaths in the United States (1). Thoracic aortic aneurysm (TAA) is one of the most common aortic pathologies worldwide (2) with complications such as aortic rupture, which can cause massive internal bleeding (3) and nearly 100% mortality (4). The risk of rupture directly correlates to the size of the aneurysm (5,6). Hence, non-invasive diagnostic modalities are required to accurately assess thoracic aortic size in TAA patients. Aortic pulsation with changes in the aortic size throughout the cardiac cycle poses a challenge to accurate assessment of these patients (3).

Computed tomography angiography (CTA) is one of the modalities used clinically to evaluate patients with known thoracic aortic disease. Several image acquisition strategies, including electrocardiography (ECG)-gating technique, have been developed to reduce cardiac pulsation artifact of the thoracic aorta CTA. Although both prospectively and retrospectively ECG-gated acquisitions are possible, the majority of clinical studies recommend prospectively triggered CTA due to lower radiation doses achieved (7) through

Department of Radiology, Northwestern Memorial Hospital, Northwestern University-Feinberg School of Medicine, Chicago, IL, USA

Corresponding author:
Vahid Yaghmai, Department of Radiology, Northwestern Memorial Hospital, Northwestern University-Feinberg School of Medicine, 676 North Saint Clair St, Suite 800 Chicago, IL 60611, USA.
Email: v-yaghmai@northwestern.edu

limiting the data acquisition to a very narrow portion of the cardiac cycle. As a result, prospective ECG-gating techniques are more susceptible to reconstruction artifacts from arrhythmia and heart rate variability.

Minimizing artifacts at ECG-gated CT is necessary for accurate measurements of the thoracic aorta. In addition to dual-source X-ray technique (8), which improves the image quality by improving the temporal resolution, premedication may also help to achieve better image quality by slowing the heart rates (9). A common approach is the use of beta-blockers, either as an intravenous push or via oral administration approximately 1 h before the imaging study. The requirement of beta-blocker premedication can be a major limitation in the process of TAA follow-up, especially when the beta-blocker administration is contraindicated or when the patient does not respond to beta-blockers. Moreover, the process of medication-induced heart rate reduction can be time-consuming. With excluding beta-blocker from thoracic aorta DSCTA protocol, there will be a reduction in preparation time prior to scan and potentially an increase in workflow in busy clinical routines. Multiple studies (9–11) have reported the positive effect of beta-blockers on image quality of coronary CTA. However, the effect of heart rate control on image quality of the ascending aorta, which is prone to significant cardiac pulsation, is not well studied. The purpose of this study was to assess the effect of beta-blockade on image quality of the ascending aorta on CTA images obtained with ECG-gated prospectively-triggered acquisitions using a dual-source scanner.

Material and Methods

Patients

This Health Insurance Probability and Accountability Act (HIPAA)-compliant study was approved by our institutional review board (IRB) for retrospective chart review. ECG-gated CTA images of the patients who were referred to our institution with suspected diagnosis of TAA or coronary heart disease between February and July 2011 were included in this study. Those with cardiac arrhythmias during scan acquisition, presence of a pacemaker or an automatic defibrillator, glomerular filtration rate (GFR) $\leq$60 mL/min, history of thoracic aortic surgery or any aortic pathology other than aortic aneurysm such as dissection or valve lesions, and patients undergoing coronary CTA with contraindications to beta-blocker administration (i.e. systolic blood pressure $<$100 mmHg, severe chronic obstructive lung disease, and left ventricular ejection fraction $<$35%) were excluded from this study. All the patients with history of oral beta-blocker administration within 24 h to the scan were also excluded from the cohort.

A total of 80 patients met inclusion criteria for this study. The study cohort was divided into two groups. Group 1 (n=40, average age 61.3 $\pm$ 11.7 years, 18 women) comprised patients with suspected diagnosis of TAA who underwent CT imaging without beta-blocker administration. Group 2 (n=40, mean age 49.7 $\pm$ 9.1 years, 12 women) comprised patients who underwent coronary CTA. All patients in group 2 had an average heart rate $>$65 beats per minute (bpm) prior to beta-blocker administration (average HR, 75.8 $\pm$ 4 bpm) and received intravenous beta-blocker before the scan based on the institutional protocol.

The BMI, mean, maximum, and minimum heart rates during scanning were recorded. Heart rate variability was calculated by subtracting the minimum heart rate from the maximum heart rate.

Image technique

All scans were performed on a dual-source CT scanner with ECG-gating capability (Somatom Definition; Siemens Medical Solutions, Forchheim, Germany). Scans in group 1 were obtained in a single breath-hold at full inspiration, from immediately above the aortic arch to the diaphragm. A fixed bolus of 110 mL of iopamidol (Isovue®370, Bracco Diagnostic Inc., Princeton, NJ, USA) was injected in the right antecubital fossa via an 18-gauge intravenous cannula at a flow rate of 5 mL/s followed by a 50 mL saline chasing bolus at the same rate, using a power injector (Medrad, Pittsburgh, PA, USA). A bolus-tracking technique was used and maximal aortic enhancement was measured by placing a 1 cm^2 region of interest (ROI) in the ascending aorta, with a triggering threshold of 115 HU. After meeting the HU threshold, the scan was initiated with a delay of 6 s. Scanning was performed in the cranio-caudal direction with prospectively triggered ECG-gating. Tube pulsing was employed with a narrow ECG acquisition window set at 70% of the R-R interval. The scan was acquired with a collimation of $2 \times 32 \times 0.6$ mm (8), gantry rotation time of 330 ms, tube current modulation (CareDose) of 170 mAs, and kVp based on patients' BMI. For this study, all patients had the BMI range of 20–30 kg/m^2, which, based on our institutional protocol, required 100 kVp setting. The data-sets were reconstructed into axial slices with a 0.75 mm thickness and a 0.4 mm slice interval (7).

The same imaging protocol was performed in group 2, using a test bolus technique, in which 20 mL of the same contrast was injected followed by 50 mL of saline. The delay time was calculated from the time of injection until the maximal enhancement in a ROI in the ascending aorta. After adding 4 s to the delay time, the estimated trigger time was used after the injection of 100 mL of the contrast material followed by 50 mL of a second phase bolus (20% contrast, 80% saline) at an injection rate of 5 mL/s (12). A total of 5 mg of beta-blocker (Metoprolol, West-Ward, Eatontown, NJ, USA) was injected intravenously immediately before the scan and re-dosed in 5-min intervals if the heart rate remained >65 bpm or until a total of 15 mg was administered. All subjects received 0.4 mg nitroglycerin (Glenmark Generics Inc., Mahwah, NJ, USA) sublingually approximately 3 min before the scan was performed.

Image analysis

Axially reformatted image data were transferred to a dedicated three-dimensional computer workstation (Leonardo; Siemens Medical Solutions, Forchheim, Germany). Images of the aorta at the level of the sinuses of Valsalva (sinus), sinotubular junction (STJ), and mid ascending aorta (MAA) at the level of the right pulmonary artery were analyzed subjectively and objectively as described below.

Subjective method

Two radiologists (VY and JC, with 10 and 3 years of experience reading thoracic aorta and coronary CTAs, respectively) scored images independently blinded to the CT protocol. Images were scored on a 3-point scale for sharpness of aortic wall based on the following scale: 1, minimum or no motion artifacts (image virtually free of image degradation), optimum for diagnosis; 2, moderate aortic wall blurring or apparent thickening of aortic wall on transverse images, adequate for diagnosis; and 3, severe motion artifacts, diagnostically inadequate.

The scores of 1 and 2 were considered as showing diagnostic image quality.

Objective method

The aortic wall edge definition was used as a quantitative score by calculating the sharpness of the wall at the three anatomic levels where the subjective analysis was performed. We used a sharpness index (SI) that has been previously defined and used in other studies (7,13). The SI was calculated using a line drawn across the aortic lumen on each of the analyzed axial slices using Image J software (Image J 1.44p, National Institutes of Health, Bethesda, MD, USA). A profile of the HU values of all pixels along the line was generated. To evaluate the SI of the vessel, first, the maximum and minimum values were noted on each side of the profile. Then, from these measurements, A (80% maximal intensity) and B (20% maximal intensity) were calculated (Fig. 1). Then, the distance between A and B was calculated on each side of the profile (d_1 and d_2) and the average of d_1 and d_2, d, was calculated and reciprocated. 1/d was used as the image SI and was reported in mm^{-1}. This means a smaller difference between 20% and 80% of the maximum HU distance (i.e. smaller d) in aortic wall indicated the "sharper aorta" (i.e. higher SI) and higher image quality. Noise was taken as the standard deviation of the aortic attenuation. Signal-to-noise ratio (SNR) was also calculated for objective comparison of the noise between two groups as follows (7):

SNR= aortic attenuation / noise

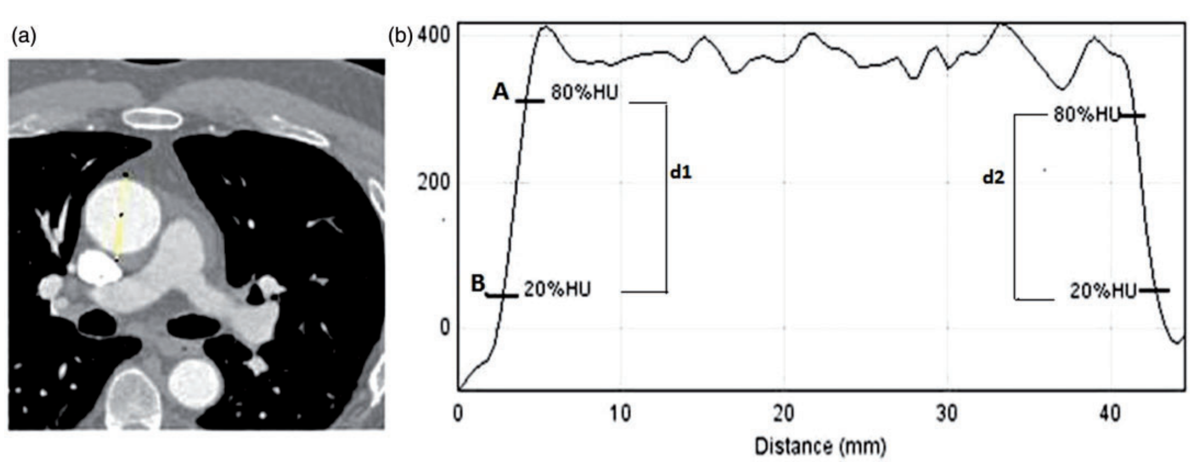

Fig. 1. (a) Transaxial image of mid ascending aorta in a 40-year-old man. Attenuation profile (b) was drawn based on the yellow line drawn across the aortic lumen. (b) The graph shows quantification of aortic wall sharpness. A, 80% maximum intensity; B, 20% maximum intensity; d_1 and d_2, distance between A and B on both sides of the profile, respectively.

Statistical analysis

Statistical analysis was performed using commercially available software (SPSS version 18.0, SPSS Inc., Chicago, IL, USA). Demographic data between the two groups were compared in terms of BMI, mean heart rate, and its variability. The subjective 3-point scores for the two reviewers were compared using the Student t-test. The average SI and SNR values for each group were also compared using the Student t-test.

Weighted kappa (k) statistics were also used to show inter-reader agreement for scoring image quality at all three levels of sinus, STJ, and MAA, where k $\leq$0.21 referred to slight agreement, 0.21–0.4 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 good agreement, and $\geq$0.81 to excellent agreement.

Results

Analysis of demographic data demonstrated comparable BMI between two groups (group 1, 25.8 kg/m$^2 \pm$ 2.7; group 2, 24.6 kg/m$^2 \pm$ 2.7; *P* value = 0.07). A significant difference was observed between groups in terms of the average heart rate at the time of scan (group 1, 72.9 bpm [range, 69.3–84.1 bpm]); group 2, 61.7 bpm [range, 58.1–63.9 bpm]), and heart rate variability (group 1 [20.3±16.7]; group 2 [12.6± 5.6]) (both *P* values <0.01) (Table 1).

SNR was comparable between the two groups (*P* value at the level of sinus, 0.52; STJ, 0.25; MAA, 0.15) (Table 2). There was no significant difference in image quality between the heart rate controlled ECG-gated and non-heart rate controlled ECG-gated groups qualitatively (*P* values of 0.25, 0.59, and 0.76 at the levels of sinus, STJ, and MAA, respectively). The mean score for all scans at all three positions was <2, indicating minimum or no motion blurring. Similarly, the image quality based on sharpness index was not significantly different between two groups at all three levels (*P* value: 0.62, 0.69, and 0.1 at sinus, STJ, and MAA, respectively). Results are summarized in Tables 3 and 4.

Good inter-rater agreement was observed between two readers at all levels in both beta-blocker (k value: 0.66, 0.75, 0.72 at sinus, STJ, and MAA, respectively)

Table 1. The table demonstrates demographic data, mean heart rate, and heart rate variability in two groups.

	Group 1	Group 2	*P* value
Patients (*n*)	40	40	
Male	22	28	
Female	18	12	
Age (years)	61.3 ± 11.7	49.5 ± 9.1	
Mean HR (bpm) (range)	72.9 (69.3–84.1)	61.7 (58.1–63.9)	<0.0001
HR variability*	20.3±16.7	12.6±5.6	0.01
BMI (kg/m^2)	25.8	24.6	0.07

*Data are shown as mean ± SD.
BMI, body mass index; Group 1, no beta-blocker premedication; Group 2, with beta-blocker premedication; HR, heart rate.

Table 2. The table demonstrates SNR at the level of sinus, sinotubular junction, and mid ascending aorta.

	Sinus	Sinotubular junction	Mid ascending aorta
Group 1*	14.6 ±3.4	15.7 ±4.6	15.5 ±3.6
Group 2*	15.0 ±3.5	14.6±3.4	14.4±3.4
P value	0.52	0.25	0.15

*Data are shown as mean ± SD
Group 1, patients who did not receive beta-blocker; Group 2, patients who received beta-blocker.

Table 3. Qualitative analysis of images at the level of sinus, sinotubular junction, and mid ascending aorta in two groups of patients.

	Sinus*	Sinotubular junction*	Mid ascending aorta*
Group 1†	1.1±0.3	1.1 ±0.2	1.0 ±0.2
Group 2†	1.0 ±0.2	1.0±0.2	1.0 ±0.2
P value	0.25	0.59	0.76

*Image quality was scored based on the 3-point scale: 1, minimum or no motion artifact (image virtually free of image degradation), optimum for diagnosis; 2, moderate aortic wall blurring or apparent thickening of aortic wall on transverse images, adequate for diagnosis; 3, severe motion artifact, diagnostically inadequate.
†Data are shown as mean ± SD.
Group 1, patients who did not receive beta-blocker; Group 2, patients who received beta-blocker.

Table 4. Quantitative analysis (sharpness index) of images at the level of sinus, sinotubular junction, and mid ascending aorta in two groups of patients.

	Sinus	Sinotubular junction	Mid ascending aorta
Group 1*	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1
Group 2*	0.6 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
P value	0.62	0.69	0.10

*Data are shown as mean ± SD.
Group 1, patients who did not receive beta-blocker; Group 2, patients who received beta-blocker.

and non-beta-blocker groups (k value at sinus: 0.65, STJ: 0.78, and MAA: 0.75).

Discussion

Given the proximity of ascending aorta to the heart, motion artifacts are common in CTA of the thoracic aorta without the use of ECG-gating technique, especially at the level of ascending aorta. Such artifacts can result in diagnostic difficulties and even misdiagnosis. Despite being the mainstay of coronary imaging (14), ECG-gated CTA can substantially reduce the motion artifacts specifically at aortic root and ascending aorta compared to the non-ECG-gated imaging, specifically when motion-free and artifact-free images are required to rule out the critical conditions such as aortic dissection or to measure aortic root diameter for presurgical planning.

The heart rate limit for diagnostic image quality is different between coronary CTA and thoracic CTA images as coronary arteries are more prone to cardiac motion artifact. The prospective ECG-gated dual-source CTA of thoracic aorta is feasible for heart rates <80 bpm (15), while the heart rate limit is 65 bpm for coronary CTA images as the artifacts caused by high heart rates are expected to have less effect when evaluating large structures such as aorta.

Although multiple studies evaluating coronary CTA have shown the impact of beta-blockade on improved image quality (9,10,16), the effect of beta-blocker administration on image quality of the ascending aorta has not been reported, yet. In routine clinical practice, the aortic root and ascending aorta are adversely affected by macroscopic motion on scans without ECG-gating. The purpose of our study was to assess the effect of beta-blockade to achieve a heart rate <65 bpm on subjective image quality and aortic wall sharpness at prospectively triggered ECG-gated dual-source CTA.

In our study, despite the significant differences in heart rate (mean HR >65 bpm in the absence of premedication *versus* mean HR <65 bpm in the presence of beta-blocker), the results of qualitative and quantitative analysis of the ascending aorta at the three levels between both groups revealed no significant difference in image quality. Our results showed good preservation of image quality by DSCTA in higher heart rates and were compatible with previous studies on coronary CTAs regarding the efficacy of DSCTA without beta-blocker premedication (13,16,17). The high temporal resolution of DSCT scanners maintained image quality in the presence of average heart rates of 73 bpm.

Beta-blocker administration has been considered useful in coronary CTA, especially in the presence of high heart rates (i.e. HR >65 bpm), when motion artifacts can significantly reduce image quality (11). Beta-blockers can be administered either orally or intravenously, with the latter being more effective in heart rate reduction in a shorter period of time (10). Despite its advantages, beta-blocker administration is contraindicated in patients with a history of severe asthma, atrioventricular nodal blockade, or low blood pressure. It is also time-consuming to control the heart rate prior to scan, specifically in institutions with high volume of scans. While significant improvement in image quality has been described with beta-blockade at coronary CTA performed by multiple investigators on single source scanners (17,18), the need for beta-blockade for coronary CTA performed on dual-source scanners is controversial (16,19,20). Ropers et al. (16) and Scheffel et al. (20) have studied image quality of coronary arteries using DSCT scanners in patients with heart rates >65 bpm. Both investigators concluded that there was a limited advantage to beta-blockade in reducing motion artifacts. The improved temporal resolution at 64-slice DSCT to 83 ms (19) enables a smaller diastolic acquisition window mitigating the requirement for a longer diastolic period. This might explain why beta-blockers have limited efficacy on image quality at coronary DSCTA at the studied heart rates.

Our study had limitations. We did not study the effect of beta-blocker in patients with non-sinus rhythms, including atrial fibrillation, or patients with other aortic pathologies such as aortic dissection. The study was retrospective and, despite the non-significant difference between the two groups in terms of BMI, it would have more power if the same cohort was used for both groups.

The results of this study should be considered regarding the fact that images were obtained using a scanner with a temporal resolution of 83 ms. Moreover, one of the study groups received nitroglycerin prior to CT scanning, which commonly results in slight increase in heart rates. This effect might reduce the real difference of heart rates between the images obtained with and without beta-blocker effect. Unfortunately, we did not have patients with no nitroglycerin administration before CT scanning. Also, we did not study the effect of beta-blocker on images acquired with scanners with lower temporal resolutions and beta-blockade premedication might be useful in improving the image quality of these scanners.

In conclusion, high resolution imaging of ascending aorta obtained with ECG-gated DSCTA may result in sufficient image quality of thoracic aorta to evaluate the aneurysm in patients with TAA. As a result, beta-blocker pre-administration and subsequent heart rate reduction may not be necessary in this setting.

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References

1. Grubb KJ, Kron IL. Sex and gender in thoracic aortic aneurysms and dissection. Semin Thorac Cardiovasc Surg 2011;23:124–125.
2. Clouse WD, Hallett JW, Schaff HV, et al. Improved prognosis of thoracic aortic aneurysms: A population-based study. JAMA 1998;280:1926–1929.
3. Hiratzka LF, Bakris GL, Beckman JA, et al. ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with thoracic aortic disease: Executive summary. A report of the American College of Cardiology Foundation/ American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. Catheter Cardiovasc Interv 2010;76:E43–E86.
4. Johansson G, Markstrom U, Swedenborg J. Ruptured thoracic aortic aneurysms: a study of incidence and mortality rates. J Vasc Surg 1995;21:985–988.
5. Coady MA, Rizzo JA, Hammond GL, et al. What is the appropriate size criterion for resection of thoracic aortic aneurysms? J Thorac Cardiovasc Surg 1997;113:476–491.
6. Mendoza DD, Kochar M, Devereux RB, et al. Impact of image analysis methodology on diagnostic and surgical classification of patients with thoracic aortic aneurysms. Ann Thorac Surg 2011;92:904–912.
7. Farrelly C, Davarpanah A, Keeling AN, et al. Low dose dual-source CT angiography of the thoracic aorta. Int J Cardiovasc Imaging 2011;27:1025–1034.
8. Flohr TG, McCollough CH, Bruder H, et al. First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol 2006;16:256–268.
9. de Graaf FR, Schuijf JD, van Velzen JE, et al. Evaluation of contraindications and efficacy of oral beta-blockade before computed tomographic coronary angiography. Am J Cardiol 2010;105:767–772.
10. Maffei E, Palumbo AA, Martini C, et al. Pharmacological management for computed tomography coronary angiography: heart rate reduction, timing and safety of different drugs used during patient preparation. Eur Radiol 2009;19:2931–2940.
11. Shapiro MD, Pena AJ, Nichols JH, et al. Efficacy of prescan beta-blockade and impact of heart rate on image quality in patients undergoing coronary multidetector computed tomography angiography. Eur J Radiol 2008;66:37–41.
12. Seifarth H, Puesken M, Kalafut JF, et al. Introduction of an individually optimized protocol for the injection of contrast medium for coronary CT angiography. Eur Radiol 2009;19:2373–2382.
13. Groves EM, Bireley W, Dill K, et al. Quantitative analysis of ECG-gated high-resolution contrast-enhanced mr angiography of the thoracic aorta. Am J Roentgenol 2007;188:522–528.
14. Roose JE, Willmann JK, Weishaupt D, et al. Thoracic aorta: motion artifact reduction with retrospective and prospective electrocardiography-assisted multi-detector row CT. Radiology 2002;222:271–277.
15. Blanke P, Bulla S, Baumann T, et al. Thoracic aorta: prospective electerocardiographically triggered CT angiography with dual-source CT-feasibility, image quality, and dose reduction. Radiology 2010;255:207–217.
16. Ropers U, Ropers D, Pflederer T, et al. Influence of heart rate on the diagnostic accuracy of dual-source computed tomography coronary angiography. J Am Coll Cardiol 2007;50:2393–2398.
17. Fine JJ, Hopkins CB, Ruff N, et al. Comparison of accuracy of 64-slice cardiovascular computed tomography with coronary angiography in patients with suspected coronary artery disease. Am J Cardiol 2006;97:173–174.
18. Nagatani Y, Takahashi M, Takazakura R, et al. Multidetector-row computed tomography coronary angiography: Optimization of image reconstruction phase according to the heart rate. Circ J 2007;71:112–121.
19. Achenbach S, Ropers D, Kuettner A, et al. Contrast-enhanced coronary artery visualization by dual-source computed tomography–initial experience. Eur J Radiol 2006;57:331–335.
20. Scheffel H, Alkadhi H, Plass A, et al. Accuracy of dual-source CT coronary angiography: first experience in a high pre-test probability population without heart rate control. Eur Radiol 2006;16:2739–2747.