Radiation Dose Reduction and Coronary Assessability of Prospective Electrocardiogram-Gated Computed Tomography Coronary Angiography: Comparison With Retrospective Electrocardiogram-Gated Helical Scan

Takao Maruyama, Masanori Takada, Toshiaki Hasuike, Atsushi Yoshikawa, Eiji Namimatsu, and Tohru Yoshizumi

J. Am. Coll. Cardiol. 2008;52;1450-1455
doi:10.1016/j.jacc.2008.07.048

Journal of the American College of Cardiology
© 2008 by the American College of Cardiology Foundation
Published by Elsevier Inc.
Vol. 52, No. 18, 2008
ISSN 0735-1097/08/$34.00
doi:10.1016/j.jacc.2008.07.048

Radiation Dose Reduction and Coronary Assessability of Prospective Electrocardiogram-Gated Computed Tomography Coronary Angiography

Comparison With Retrospective Electrocardiogram-Gated Helical Scan

Takao Maruyama, MD, PhD,* Masanori Takada, MD,* Toshiaki Hasuike, MD,* Atsushi Yoshikawa, MD,* Eiji Namimatsu, RT,† Tohru Yoshizumi, RT*‡

Kobe and Osaka, Japan

Objectives The aim of this study was to evaluate radiation dose and coronary assessability of a prospective electrocardiogram (ECG)-gated scan by 64-slice multidetector (row) computed tomography (MDCT)-coronary angiography (CA) compared with a retrospective ECG-gated helical scan.

Background The 64-slice MDCT-CA has been widely used; however, a high radiation dose by 64-slice MDCT-CA has been reported. Prospective ECG-gated scan using "step-and-shoot" protocol can reduce radiation exposure effectively.

Methods MDCT-CA was performed in 229 consecutive patients. Fifty-six patients were excluded because of higher heart rates of >65 beats/min; of patients with heart rates ≤65 beats/min, 97 were analyzed by helical scan with tube current modulation and 76 were analyzed by prospective gating. Coronary assessability and diagnostic accuracy were investigated in comparison with selective CA as the gold standard. Radiation doses were evaluated in both protocols.

Results Coronary assessability of helical scan was 95.5% (1,303 of 1,364 segments), while that of prospective gating was 96.6% (1,053 of 1,089 segments), showing similar coronary assessability ($p = 0.14$). Sensitivity and specificity for coronary obstructive and occlusive lesions in the assessable segments were 97.0% (162 of 167) and 97.6% (1,109 of 1,136) by helical scan, while those of prospective gating were 96.4% (81 of 84, $p = 0.84$) and 98.5% (955 of 969, $p = 0.12$), respectively. Effective doses of helical scan and prospective gating were 21.1 ± 6.7 mSv and 4.3 ± 1.3 mSv, respectively ($p < 0.0001$), showing that prospective gating decreased radiation dose by 79% compared with that of helical scan.

Conclusions MDCT-CA by prospective gating showed equivalent coronary assessability and diagnostic accuracy with decreased radiation dose in comparison with a retrospective ECG-gated helical scan with tube current modulation. (J Am Coll Cardiol 2008;52:1450–5) © 2008 by the American College of Cardiology Foundation

In recent years, multidetector (row) computed tomography (MDCT) has been introduced and widely used for noninvasive evaluation of coronary arteries. The latest 64-slice MDCT-coronary angiography (CA) with retrospective electrocardiogram (ECG) gating has high assessability and diagnostic accuracy (1–5); however, a high radiation dose from 64-slice MDCT-CA has been noticed (6–8), and it may be related to a higher incidence of cancer (8). For dose reduction, an ECG-triggered dose modulation algorithm that reduces the tube current by 80% during the systolic phase can decrease the radiation dose by approximately 20% (9). Recently, a prospective ECG-gated scan for MDCT-CA has been developed, which reduces radiation dose more effectively by the "step-and-shoot" protocol (10,11). Therefore, we investigated the radiation dose and coronary assessability of coronary computed tomography (CT) an-

See page 1456

From the Departments of *Cardiology and †Radiology, Kawasaki Hospital, Kobe, Japan; and the ‡Department of Internal Medicine and Molecular Science, Graduate School of Medicine, Osaka University, Osaka, Japan.

Manuscript received February 12, 2008; revised manuscript received June 23, 2008, accepted July 10, 2008.

giography by prospective gating, and compared it with retrospective ECG-gated helical scan with dose modulation.

Methods

Subjects. A total of 273 consecutive patients were enrolled between December 2006 and November 2007 because of suspected coronary artery disease or follow-up after coronary intervention. Exclusion criteria included arrhythmias such as atrial fibrillation and frequent premature contractions, coronary bypass grafts, and renal insufficiency; 44 patients were excluded for these reasons, and 229 patients underwent MDCT-CA. The study period was from December 2006 to June 2007 for helical scan and from July 2007 to November 2007 for prospective gating (Fig. 1). Before CT examination, patients with heart rates (HRs) higher than 70 beats/min were administered oral beta-blockers (metoprolol, 20 mg). Patients with HRs of >65 beats/min during CT examination were excluded from analysis because of the different reconstruction method: step-and-shoot protocol only permits a "half-reconstruction" method, and in patients with HRs of >65 beats/min, "multisector reconstruction" is recommended instead of half-reconstruction due to the insufficient ECG gating. Therefore, 56 patients were excluded from this analysis because of higher HRs, and 97 and 76 consecutive patients with HRs of ≤65 beats/min were investigated by retrospective ECG-gated helical scan and prospective gating, respectively. Selective angiography was performed within 2 months after CT examination in order to confirm the diagnosis of coronary artery disease or to restudy after intervention. Study protocols were in accord with ethical standards of the hospital, and approved by the Ethical Committee of the hospital. Written informed consent was obtained from all patients.

MDCT-CA by helical scan. MDCT data were acquired using LightSpeed VCT (GE Healthcare, Waukesha, Wisconsin). ECG monitoring was performed continuously during the examination. First, a scout scan was performed in inspiratory breath-hold to gain a sagittal and coronal view for positioning of the entire heart. A region of interest was positioned at the center of the ascending aorta; then, a test bolus (10 ml) of the iodinated contrast agent iohexol (350 mgI/ml) was injected intravenously at 4.0 ml/s with a saline chase of 20 ml at 5.0 ml/s. The time interval between bolus injection and maximal enhancement in the ascending aorta was measured, and the starting time of the enhanced scan was calculated as 3 s after transit time of the contrast agent. Then 0.7 ml/kg body weight of contrast agent was injected, followed by a saline chase of 30 ml, and the scan was started with the delay time determined previously with 64 × 0.625 mm collimation. The gantry rotation time was 0.35 s, and the tube current was 800 mA at 120 kV with dose modulation of 70% to 80% of RR interval (Fig. 2A). All acquired data were transferred to a computer workstation (Advantage Workstation 4.3, GE Healthcare) and reconstructed by the half-reconstruction method. The effective slice thickness was 0.625 mm, and the reconstruction increment was approximately 0.5 mm. The dataset with the

Abbreviations and Acronyms

CA = coronary angiography

CT = computed tomography

$CTDI_{vol}$ = computed tomography dose index volume

HR = heart rate(s)

MDCT = multidetector (row) computed tomography

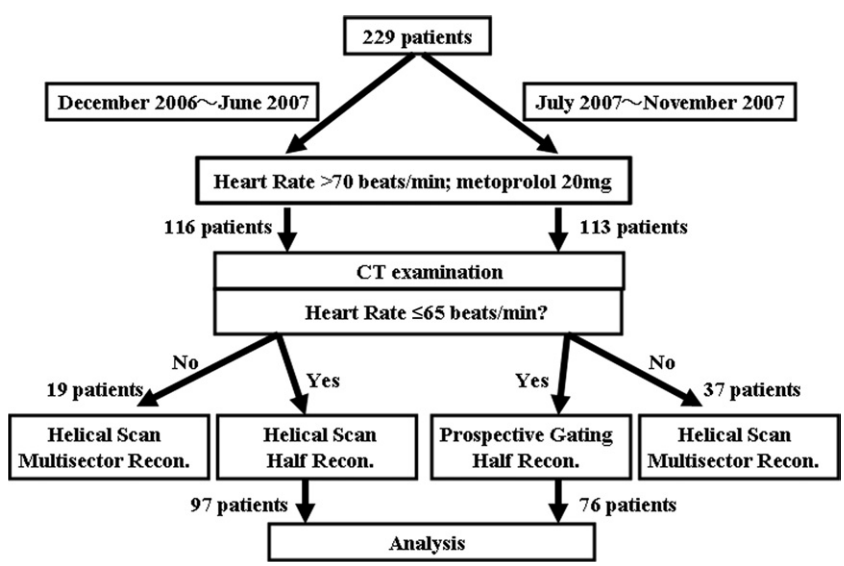

Figure 1 Study Protocol

CT = computed tomography; Recon. = reconstruction.

JACC Vol. 52, No. 18, 2008
October 28, 2008:1450–5

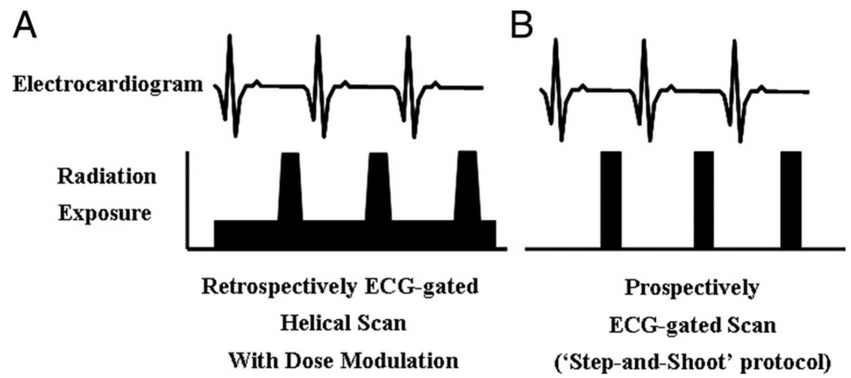

Figure 2 **Schematic Illustration of Radiation Exposure in Helical Scan and Prospective Gating**

(A) Helical scan; **(B)** prospective gating. ECG = electrocardiogram.

best image quality containing the fewest artifacts was selected for visualization of each coronary artery.

MDCT-CA by prospective gating. Preparation, contrast media injection, and data reconstruction were similar to those of helical scan. Data acquisition was performed within 3 to 4 beats at mid-diastolic phase (around 75% of RR interval) by step-and-shoot protocol (SnapShot Pulse, GE Healthcare) (Fig. 2B). The gantry rotation time was 0.35 s, and tube current was 800 mA at 120 kV with average padding time of 30.4 ms (range 0 to 50 ms, according to the HR variability). It is noteworthy that prospective gating was the initial acquisition mode (12) applied in the pioneering study on cardiac CT imaging (13), and that temporal resolution of CT scanners has been insufficient to visualize coronary arteries until the introduction of fast gantry rotation times.

Evaluation of MDCT-CA. First, each coronary segment including branches was identified by maximal intensity projection and coronary tree images; then, curved multiplanar reformatted and cross-sectional images of each segment were created and evaluated (Fig. 3). Image quality of each segment was evaluated, and assessability was determined

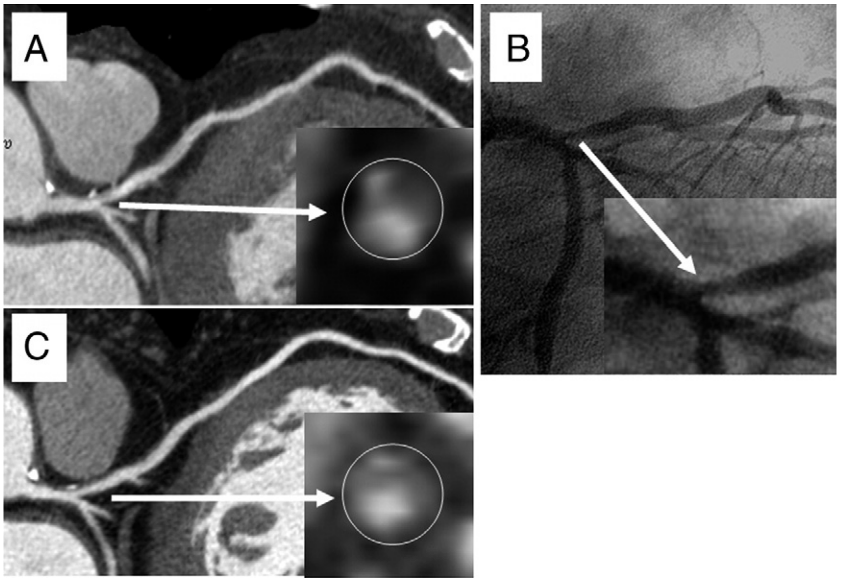

Figure 3 **Reconstructed Coronary Images of Helical Scan and Prospective Gating**

(A) Curved multiplanar reformatted and cross-sectional images by helical scan. Left anterior descending artery of 58-year-old man who was suspected of exhibiting effort angina is shown, and a partially calcified plaque was observed **(arrow)**. Estimated effective dose: 22.8 mSv. **(B)** Selective angiography of the same patient. Moderate coronary stenosis is observed in the same position as in **panel A** as detected by multidetector (row) computed tomography coronary angiography. A myocardial perfusion test revealed no ischemia (not shown); therefore, this patient was treated medically. **(C)** Multidetector (row) computed tomography coronary angiography follow-up by prospective gating 6 months after angiography in the same patient. Similar image quality was obtained. Estimated effective dose: 4.0 mSv.

Table 1 Patient Characteristics

	Helical	Prospective	p Value
Patients	97	76	
Age (yrs)	69.1 ± 9.4 (44–89)	69.9 ± 9.9 (46–87)	0.57
Gender (male/female)	71/26	47/29	0.11
Body mass index (kg/m^2)	24.0 ± 3.2 (16.4–39.8)	23.9 ± 4.6 (16.0–42.6)	0.89
Reasons for CT coronary angiography			
Suspected CAD	59 (61)	49 (64)	0.62
Stent follow-up	38 (39)	27 (36)	
Coronary risk factors			
Hypertension	69 (71)	60 (79)	0.24
Dyslipidemia	62 (64)	52 (68)	0.53
Diabetes mellitus	44 (45)	38 (50)	0.54
Heart rates during examination (beats/min)			
Average	56.1 ± 5.8 (32–65)	54.6 ± 6.9 (34–65)	0.21
Range	2.5 ± 1.8 (0–9)	3.0 ± 2.5 (0–13)	0.14

Values are mean ± SD (range) or n (%).
CAD = coronary artery disease; CT = computed tomography.

according to the American Heart Association 15-segment model (14). Segments with "excellent" (excellent quality) and "good" (good quality, assessable for stenosis) images were judged as "assessable" (15). Segments with "fair" (fairly visualized, nonassessable) and "poor" (poorly or not visualized) images were judged as "nonassessable." Visualized coronary stenoses were classified by 3 grades such as normal-to-mild (≤50%), obstructive (>50%, nonocclusive), and occlusive (100%). In nonassessable segments, causes responsible for nonassessability were evaluated (15). Segments with implanted coronary stents were excluded from this study.

Radiation dose. Computed tomography dose index volume ($CTDI_{vol}$) (mGy) was provided by the CT scanner and multiplied by scan length (cm) in order to obtain dose-length product (mGy · cm) (7,8). To obtain the effective dose (mSv), dose-length product was multiplied by the appropriate conversion factor for the chest (0.017 mSv/[mGy · cm]).

Selective angiography. Selective CA was performed by the standard method. The angiograms were evaluated by quantitative coronary analysis with vessel contour detection after catheter-based image calibration. Coronary stenotic lesions were classified by grades: normal-to-mild (diameter reduction ≤50%), obstructive (diameter reduction of >50%, nonocclusive), and occlusive, and compared with those of MDCT-CA.

Table 2 Assessability of Coronary Segments by Helical Scan and Prospective Gating

	Helical	Prospective	p Value
Patients	97	76	
Segments	1,364	1,089	
Assessable segments	1,303 (95.5)	1,053 (96.6)	0.14
Nonassessable segments	61 (4.5)	36 (3.4)	
Cause for nonassessablity			
Massive calcium	56 (92)	33 (92)	0.98
Motion artifacts	5 (8)	3 (8)	

Data are expressed as numbers of segments (%).

Statistical analysis. Data were expressed as mean ± SD (ranges) or percentages. Statistical analyses were performed by the Mann Whitney *U* test and chi-square test.

Results

Patient characteristics are shown in Table 1, showing no significant differences between patients' age, gender, body mass index, risk factors, and HR during CT examination. No serious arrhythmias were observed during data acquisition, and no patients underwent repeated enhanced scan.

Table 2 demonstrates assessability of coronary segments by helical scan and prospective gating, showing that prospective gating has similar coronary assessability to that of helical scan. The cause for nonassessability was mostly massive calcium deposits of coronary segments.

A patient-based analysis of coronary assessability is shown in Figure 4. Prevalence of patients in whom all entire coronary segments were assessable was 85% (82 of 97) by helical scan, while that of prospective gating was 86% (65 of 76), demonstrating equivalent coronary assessability of both

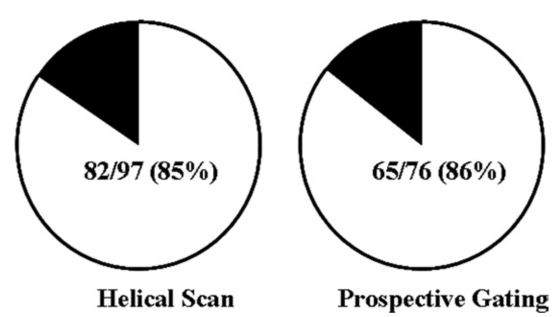

Figure 4 Patient-Based Coronary Assessability

Prevalence of patients in whom all coronary artery segments were assessable is shown.

JACC Vol. 52, No. 18, 2008
October 28, 2008:1450–5

Table 3 Diagnostic Accuracy of Helical Scan and Prospective Gating

	Selective Coronary Angiography		
	Normal-Mild (≤50%)	Obstructive (>50%)	Occlusive (100%)
Helical scan (1,364 segments)			
Normal-to-mild (≤50%)	1,109	5	0
Obstructive (>50%)	27	147	0
Occlusive (100%)	0	0	15
Nonassessable	41	17	3
Prospective gating (1,089 segments)			
Normal-to-mild (≤50%)	955	3	0
Obstructive (>50%)	14	73	0
Occlusive (100%)	0	0	8
Nonassessable	21	14	1

Data are expressed as numbers of segments.

protocols ($p = 0.84$). Diagnostic accuracy of MDCT-CA in comparison with selective angiography is shown in Table 3.

Sensitivities for obstructive and occlusive coronary lesions in assessable segments by helical scan and prospective gating were 97.0% (162 of 167) and 96.4% (81 of 84), respectively ($p = 0.84$, 95% confidence interval: 0.19 to 3.6), while specificities were 97.6% (1,109 of 1,136) and 98.5% (955 of 969), respectively ($p = 0.12$, 95% confidence interval: 0.86 to 3.2), demonstrating similar diagnostic values.

Patient-based diagnostic values were evaluated by investigating and comparing maximal stenotic grades of the coronary arteries in patients in whom all coronary segments were assessable by MDCT-CA, with selective angiography as the gold standard. Sensitivity, specificity, and accuracy of coronary obstructive and occlusive lesions by helical scan ($n = 82$) were 96% (48 of 50), 94% (30 of 32), and 95% (78 of 82), respectively, while those by prospective gating ($n = 65$) were 100% (27 of 27), 92% (35 of 38), and 95% (62 of 65), respectively, showing similar diagnostic values ($p = 0.29$, 0.79, and 0.94, respectively).

Table 4 demonstrates radiation doses of helical scan and prospective gating, showing that exposure time, $CTDI_{vol}$, dose-length product, and effective dose of prospective gating were significantly lower than those of helical scan with dose modulation. Estimated effective doses of helical scan and prospective gating were 21.1 ± 6.7 mSv and 4.3 ± 1.3 mSv, respectively, revealing that prospective gating enabled dose reduction by 79% compared with dose-modulated helical scan.

Discussion

In the current study, we investigated radiation dose and coronary assessability of 64-slice MDCT-CA by prospective ECG-gated scan, and demonstrated that prospective gating has equivalent coronary assessability to that of retrospective ECG-gated helical scan in patients with a lower HR of ≤65 beats/min. The effective dose of prospective gating was estimated to be approximately 4.3 mSv, which is lower than that of the reported diagnostic selective angiography (5 to 6 mSv) (16,17), suggesting that step-and-shoot protocol is useful, especially in patients who undergo radiation exposure repetition, such as follow-up after coronary intervention.

The effective dose of prospective gating in this study was higher than that in the previous report (11): it was speculated that the increase in radiation dose was caused by the use of padding. The HR variability of patients in this study was more remarkable than that in the previous report, and average padding time of 30.4 ms was added according to the grades of HR variability in order to find an optimal time period during the diastolic phase in patients with HR variations, to minimize the "stair-step" artifacts (11), which resulted in the increase in dose exposure. Although no stair-step artifacts were observed in this study, it is obvious that setting the padding function to "off" will minimize radiation dose, and appropriate setting of the padding is disputable in patients with marked HR variability.

Study limitations. One of the limitations of prospective gating is that it could not be applied in patients with a higher HR, because step-and-shoot protocol permits only the half-reconstruction method, and its application is limited only to patients with a lower HR: a significant proportion of patients had to be excluded because of the higher HR. To use step-and-shoot protocol in patients with a higher HR, administration of a beta-blocker is essential.

Arrhythmias may affect image quality because of insufficient ECG gating in MDCT-CA. In this study, no serious arrhythmias were observed; however, as exposure time of prospective gating is short and limited in the mid-diastolic phase, adequate editing and searching for optimal time phase could not be performed in patients with arrhythmias, and restudy may be needed if serious arrhythmias occurred during data acquisition.

Another limitation of this study was that patients were not randomized to 2 different protocols, which may lead to

Table 4 Radiation Doses of Helical Scan and Prospective Gating

	Helical	Prospective	p Value
Exposure time (s)	7.7 ± 1.4 (6.1–14.0)	0.9 ± 0.1 (0.7–1.0)	<0.001
$CTDI_{vol}$ (mGy)	79.7 ± 18.0 (38.6–121.6)	19.0 ± 5.4 (9.3–33.5)	<0.001
Dose-length product (mGy · cm)	1,242.2 ± 392.5 (629.6–2,558.7)	255.2 ± 76.3 (97.2–468.4)	<0.001
Effective dose (mSv)	21.1 ± 6.7 (10.7–43.5)	4.3 ± 1.3 (1.6–7.9)	<0.001

Values are mean ± SD (range).
$CTDI_{vol}$ = computed tomography dose index volume.

a bias. Prospective ECG gating represents an important step forward in MDCT-CA, but it is not a mature technique and has several weaknesses. Nevertheless, this protocol has great potential in combination with further required improvement in MDCT-CA technique, such as higher rotation speed and increasing numbers of detectors allowing full heart coverage.

Reprint requests and correspondence: Dr. Takao Maruyama, Department of Cardiology, Kawasaki Hospital, 3-3-1, Higashiyama, Hyogo, Kobe 652-0042, Japan. E-mail: maruyama_takao@kawasaki-hospital-kobe.or.jp.

REFERENCES

1. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 2005;46:552–7.
2. Leber AW, Knez AK, von Ziegler F, et al. Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 2005;46:147–54.
3. Leschka S, Alkadhi H, Plass A, et al. Accuracy of MSCT coronary angiography with 64-slice technology: first experience. Eur Heart J 2005;26:1482–7.
4. Pugliese F, Mollet NR, Runza G, et al. Diagnostic accuracy of non-invasive 64-slice CT coronary angiography in patients with angina pectoris. Eur Radiol 2006;16:565–82.
5. Ropers D, Rixe J, Anders K, et al. Usefulness of multidetector row computed tomography with 64 × 0.6-mm collimation and 30-ms rotation for the noninvasive detection of significant coronary stenoses. Am J Cardiol 2006;97:343–8.
6. Hausleiter J, Meyer T, Hadamitzky M, et al. Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different protocols on effective dose estimates. Circulation 2006;113:305–10.
7. Nickoloff EL, Alderson PO. A comparative study of thoracic radiation doses from 64-slice cardiac CT. Br J Radiol 2007;80:537–44.
8. Einstein JA, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. JAMA 2007;298:317–23.
9. Stolzmann P, Scheffel H, Schertler T, et al. Radiation dose estimates in dual-source computed tomography coronary angiography. Eur Radiol 2008;18:592–9.
10. Hsieh J, Londt J, Vass M, Li J, Tang X, Okerlund D. Step-and-shoot data acquisition and reconstruction for cardiac x-ray computed tomography. Med Phys 2006;33:4236–48.
11. Husmann L, Valenta I, Gaemperli O, et al. Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. Eur Heart J 2008;29:191–7.
12. Hounsfield GN. Computed medical imaging. Science 1980;210:22–8.
13. Daniel WG, Döhring W, Lichtlen PR, Stender HS. Non-invasive assessment of aortocoronary bypass graft patency by computed tomography. Lancet 1980;1:1023–4.
14. Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease. Circulation 1975;51:5–40.
15. Maruyama T, Yoshizumi T, Tamura R, et al. Comparison of visibility and diagnostic capability of noninvasive coronary angiography by eight-slice multidetector-row computed tomography versus conventional coronary angiography. Am J Cardiol 2004;93:537–42.
16. Coles DR, Smail MA, Negus IS, et al. Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography. J Am Coll Cardiol 2006;47:1840–5.
17. Zanzonico P, Rothenberg LN, Strauss HW. Radiation exposure of computed tomography and direct intracoronary angiography: risk has its reward. J Am Coll Cardiol 2006;47:1846–9.

Key Words: CT coronary angiography ▪ dose reduction ▪ prospective gating ▪ step-and-shoot.