Multislice Computed Tomography as a Routine Diagnostic Modality for Assessing Coronary Artery Disease: Our Initial Experience with a Novel ECG-gated Image Reconstruction Method

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Abstract：Recent development in non-invasive cardiovascular imaging has now permitted direct visualization of the coronary artery. Multislice spiral computed tomography (MSCT) seems the most promising modality for coronary artery imaging. However, coronary artery imaging is often obscure because cardiac motion artifact (CMA) is limited to temporal resolution. We developed a novel ECG-gated image reconstruction method which reduces CMA. This article describes the usefulness of MSCT in detecting coronary artery disease as well as detecting and evaluating coronary artery plaques. In addition, coronary artery abnormalities in Kawasaki disease and congenital coronary artery anomaly are demonstrated.
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Key words: multislice spiral computed tomography (MSCT), coronary artery disease, coronary artery plaque, Kawasaki disease, coronary artery anomaly

Introduction

There is no doubt that direct visualization of the coronary artery is an ultimate goal for non-invasive diagnosis of the coronary artery disease (CAD). Recent development in imaging modalities such as magnetic resonance imaging (MRI),[1, 2] electron beam computed tomography (EBCT)[3, 4] and multislice spiral computed tomography (MSCT)[5-8] have enabled accurate morphological assessment of the coronary artery system. However, MRI and EBCT have a limitation that spatial resolution is approximately 2.0 mm which is insufficient for coronary artery imaging. MSCT provides excellent spatial resolution up to 0.5 mm and allows interpretation of not only major coronary arteries but also their branches.[8] In addition, MSCT is capable of detecting coronary artery plaques with its high spatial resolution and ability to quantify the CT density.[9] In this article, we describe our initial experience in over 900 patients with suspected CAD.

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Methods

Patients

In general, MSCT can be performed in all the patients unless they have contraindications such as (1) renal dysfunction (serum creatinine>1.5 mg/dl), (2) chronic obstructive pulmonary disease who are contraindicated to beta blockers, (3) severe left ventricular systolic dysfunction as defined by the left ventricular ejection fraction<0.3, (4) hyperthyroidism, (5) pregnancy and (6) cardiac arrhythmias including chronic atrial fibrillation and frequent premature contractions.

Premedications

One of the major drawbacks of MSCT is its limited temporal resolution. It ranges from 200 ms (16-detector-row) to 250 ms (4-detector-row) when the single-phase algorithm (one image reconstruction by single cardiac cycle) is performed. Thus, lowering heart rate (below 64/min for 4-detector-row and 72/min for 16-detector-row equipments) is essential for cardiac imaging without cardiac motion

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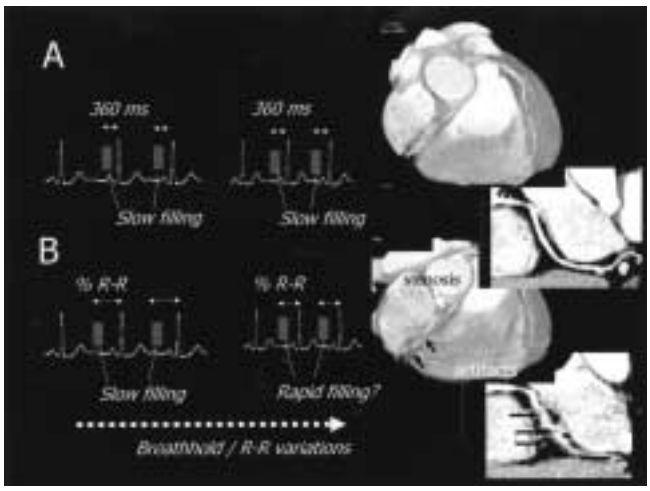


Figure 1 Our ECG-gated reconstruction method which avoids cardiac motion artifact occurring during the rapid filling and atrial contraction periods (A). The conventional ECG-gated reconstruction method which utilizes percent R-R intervals results in contamination with motion artifact on the z-axis (B).

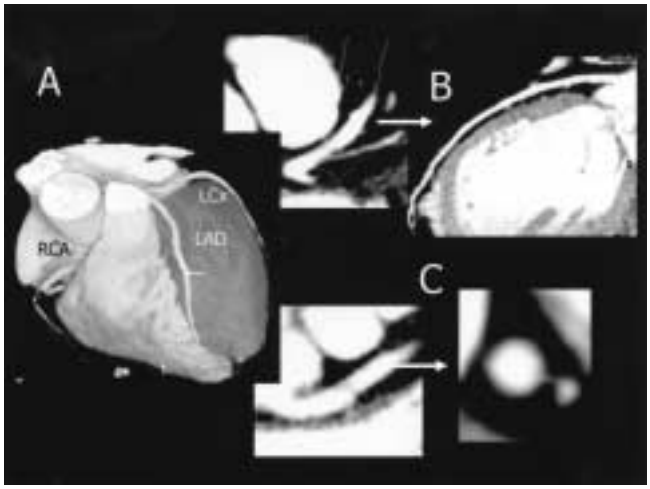


Figure 2 Routine image processing and analysis. Volume rendering (A), curved MPR (B) and cross-sectional (C) images.
LAD: left anterior descending artery, LCx: left circumflex artery, RCA: right coronary artery

artifact (CMA). We administer 20–60 mg of metoprolol 60–90 minutes prior to the scan. Nitroglycerin spray (0.3 mg) is also given sublingually 5 minutes prior to the scan.

Scan protocol

In our institute, MSCT is performed using a Siemens SOMATOM Volume Zoom which provides a 4-detector-row gantry. All the image acquisitions are performed in inspiratory breathhold preceded by inhalation of oxygen (4 L/min) for 5 minutes. After imaging at the level of the carina and positioning the region of interest (ROI) in the center of the ascending aorta, a bolus of 18 ml of the non-ionic contrast medium is injected intravenously and the time interval between contrast agent injection and the maximum enhancement within the ROI is measured. The remainder of the contrast medium (82 ml) is then injected and the scan was started with a delay according to the previously determined contrast transit time. The volume data set for coronary artery imaging is acquired in spiral mode, with simultaneous acquisition of 4 parallel slices (1.0 mm collimation each, table feed 1.5 mm/rotation, 140 kV, 320 mA and the gantry rotation time 500 ms), which allows temporal resolution of 250 ms. The patient's ECG is digitized and continuously monitored during the scan period.

Image reconstruction, processing and analysis

The raw data of the scans are reconstructed using a single-phase algorithm in all the patients as described previously.[5-8] We developed a new ECG-gated, retrospective image reconstruction technique to reduce CMA. This technique has demonstrated the substantial reduction in CMA occurrence during the ventricular rapid filling and atrial contraction periods.[8] In brief, the reconstruction window (250 ms) is positioned by inputting the absolute time (ms) backward from the next R waves so that the end of the reconstruction period was set at the peak of the P wave on monitor ECG (**Fig. 1A**). This image reconstruction technique is superior in terms of CMA to the technique that utilizes the percent R-R interval as a reference (**Fig. 1B**). After processing volume rendering (3D) images, curved multiplanar reconstruction (MPR) images and cross-sectional MPR images are obtained (**Fig. 2**). Images are carefully inspected for coronary artery stenosis and plaques in the major coronary artery branches including the left main coronary artery (LMCA, #5), the left anterior descending artery (LAD, #6–#8), the left circumflex artery (LCx, #11 and #13) and the right coronary artery (RCA, #1–#4). The major side branches such as the diagonal arteries (#9), the obtuse marginal artery (#12–1) and the right ventricular branches (RV) are also inspected. The whole analytic procedure requires only 10–20 minutes per patient.

Accuracy of MSCT for the detection of CAD

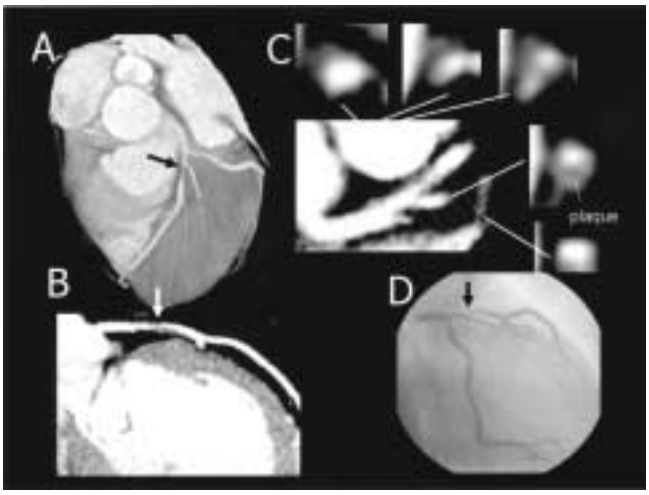
The accuracy of MSCT in diagnosis of CAD depends largely on the image quality. For example, in the study by Achenbach et al.,[7] only 68% of the coronary arteries were assessable. Although the sensitivity and specificity in detecting coronary artery stenoses in the assessable arteries were fair (91% and 84%, respectively), the overall sensitivity was low (58%) when nonassessable arteries were included. The major causes of nonassessability were CMA (39 of the 256 arteries) and severe calcification (27 of the 256 arteries). In the recent report by Vogl et al.,[10] the sensitivity in detecting significant coronary artery stenoses was even lower (74.7%) because of poor image quality due to CMA. Only 74% of the coronary arteries were visualized and assessable without cardiac motion artifact even at low heart rates <60/min. Using our ECG-gated image reconstruction technique, artifact-free coronary images can be obtained in the majority of patient.[8] We demonstrated a high sensitivity (94%) and specificity (97%) in diagnosing significant coronary artery stenoses in 54 consecutive patients.[11]

Application to acute coronary syndrome

The management of patients with suspected acute coronary syndrome (ACS) in the emergency department still remains a challenge even with current diagnostic modalities. MSCT certainly deserves attention to be a powerful diagnostic tool for detecting ACS, particularly when the typical clinical manifestation of acute ischemia is absent. **Fig. 3** demonstrates MSCT images of a 44-year-old man who was admitted to the coronary care unit (CCU) of our hospital with strong anterior chest pain persisting for 30 minutes. He had no risk factors such as diabetes mellitus, hypercholesterolemia, obesity or smoking. His ECG was normal and his laboratory data including serum troponin T and creatine kinase were normal. MSCT was performed immediately after his admission. Volume rendering (A), curved (B) and cross-sectional MPR images (C) demonstrates high-grade luminal narrowing at the proximal portion of the LAD with a CT-low-dense mass suggesting a soft plaque. The diagnosis of ACS was made and he underwent CAG immediately after the MSCT scan, which revealed the same diagnosis (D). He underwent stent implantation into the LAD. Thus, we routinely perform MSCT scans in patients with suspected ACS unless they manifest ST-segment elevation.

Evaluation of coronary artery plaques

The most important role of MSCT in the diagnosis of CAD may be detection and characterization of the texture of coronary artery plaques. Capability of MSCT in differentiating soft plaques from fibrous or hard plaques has been reported by Schroeder et al.[9] and by us.[12] In these reports, soft plaques containing lipid-rich cores consisted of CT density less than 50 Hounsfield Units (HU). We also have demonstrated that the CT density of the plaque in patients with ACS (n=20) is significantly lower than that in patients with stable angina (n=22) with little overlaps between the two groups (31±13 HU and 72±20 HU, respectively, **Fig. 4**). Plaques in a patient with stable angina and ACS are depicted



A | C
B | D

Figure 3 MSCT and angiographic images in a patient with suspected acute coronary syndrome. Volume rendering (A), curved MPR (B), cross-sectional MPR (C) images and coronary angiogram (D).

in **Figs. 5 and 6**.

Other clinical applications

MSCT has now become the standard diagnostic modality for adolescents and young adults with Kawasaki disease in our institute. In our recent report in 5 patients, we have demonstrated complete agreement between CAG and MSCT as to coronary artery aneurysms, significant stenoses and occlusions.[13-14] **Fig. 7** represents MSCT images in a 20-year-old man who has a history of Kawasaki disease at the age of 5. He had a giant coronary artery aneurysm in the LMCA and the LAD. The RCA had a braid-like, multi-layered appearance, a finding suggesting the occlusion-recanalization sequence during the process of acute vasculitis.

Congenital coronary artery anomalies may also be a category for which MSCT can be a first choice of diagnostic procedures. For example, **Fig. 8** demonstrates a 70-year-old man who presented symptoms of congestive heart failure. MSCT clearly documents an anomalous vessel connecting between the LCx and the right atrium. The LCx is markedly dilated and tortuous, accompanied by multiple cystic structures.[15]

Future directions

The major drawback of MSCT is its limited temporal resolution. 16-detector-row equipments which provide 180–210 ms temporal resolution and 0.5 mm spatial resolution are now available, but they need more development to achieve CMA-free imaging. Future development in the hardware will engage visualization of more details of coronary artery morphology including fibrous caps of the plaque, coronary capillary vessels and collateral vessels.

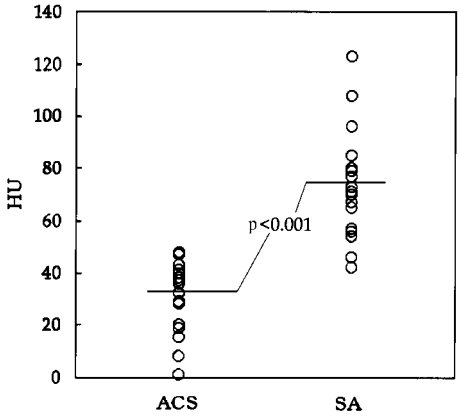


Figure 4 CT density of the patients with acute coronary syndrome (ACS) and stable angina (SA).
HU: Hounsfield units

In conclusion, MSCT has potential not only to detect significant coronary artery stenoses or occlusions, but also to predict the future coronary events in asymptomatic patients with high likelihood of CAD.

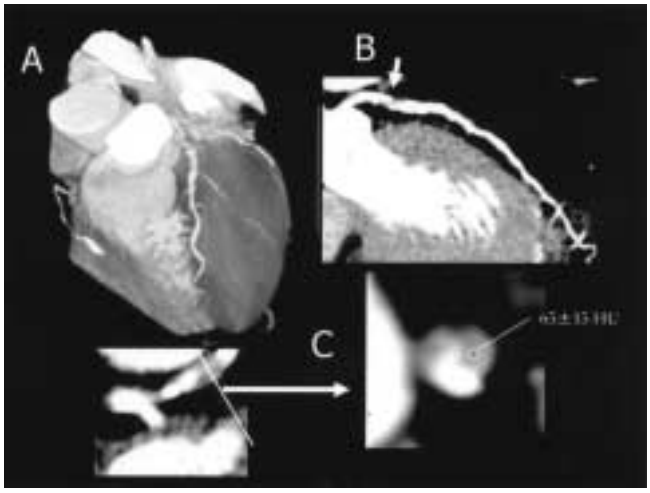


Figure 5 Volume rendeting (A), curved MPR (B) and cross-sectional MPR (C) images in a patient with stable angina. The plaque density is relatively high (65±15 HU).

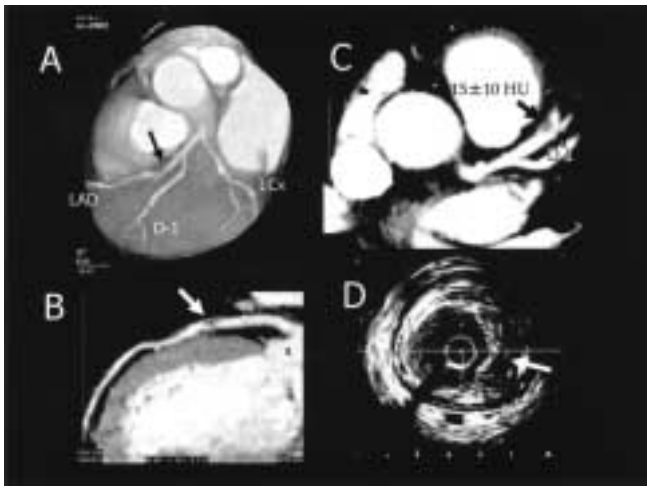


Figure 6 Patient with acute anterior myocardial infarction. Volume rendering (A) and curved MPR (B) images depict stenosis at the LAD (arrows). Axial image (C) shows a plaque with the CT density of 15±10 HU. Intracoronary ultrasoud (D) shows a plaque with a lipid-rich core (arrow).
D-1: first diagonal artery
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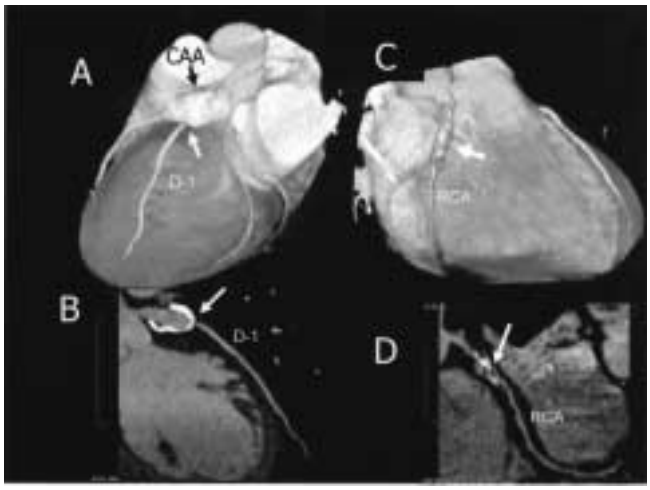

Figure 7 MSCT images of a patient with Kawasaki disease. A huge coronary artery aneurysm (CAA) and significant stenosis at the first diagonal artery are demonstrated (A, B). There is a braid-like, multi-layered structure at the RCA (C, D).
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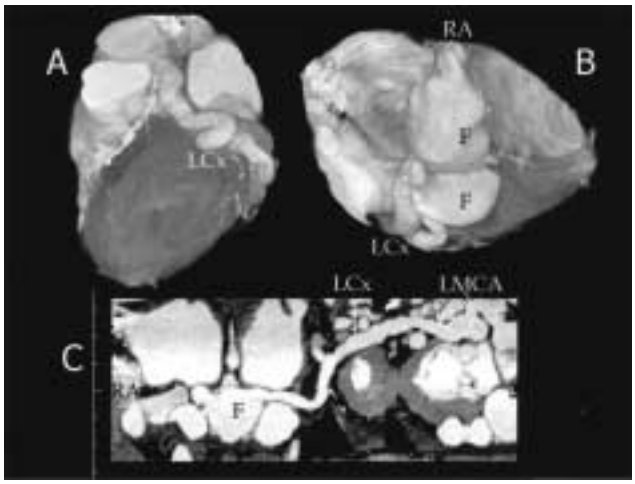

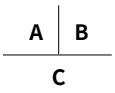

Figure 8 A 70-year-old patient with a congenital LCx-right atrium (RA) arteriovenous fistula. Volume rendering images from the left anterior oblique (A) and bottom (B) views demonstrate markedly dilated, tortuous LCx and multiple cystic structures. Curved MPR image (C) shows the drainage of the fistula into the RA.
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References

1) Taylor AM, Jhooti P, Wiesmann F et al: MR navigator-echo monitoring of temporal changes in diaphragm position: Implications for MR coronary angiography. J Magn Reson Imaging, 1997, **7**: 629–636.
2) Danias PG, McConnell MV, Khasgiwala VC et al: Prospective navigator correction of image position for coronary MR angiography. Radiology, 1997, **203**: 733–736.
3) Achenbach S, Moshage W, Bachmann K: Detection of high-grade restenosis after PTCA using contrast-enhanced electron beam CT. Circulation, 1997, **96**: 2785–2788.
4) Achenbach S, Moshage W, Ropers D et al: Value of electron-beam computed tomography for the noninvasive detection of high-grade coronary-artery stenoses and occlusions. New Engl J Med, 1998, **339**: 1964–1971.
5) Ohnesorge B, Flohr T, Becker C et al: Cardiac imaging by means of electrocardiographically gated multisection spiral CT: Initial experience. Radiology, 2000, **217**: 564–571.
6) Achenbach S, Ulzheimer S, Baum U et al: Noninvasive coronary angiography by retrospectively ECG-gated multislice spiral CT. Circulation, 2000, **102**: 2823–2828.
7) Achenbach S, Giesler T, Ropers D et al: Detection of coronary artery stenoses by contrast-enhanced, retrospectively electrocardiographically-gated, multislice spiral computed tomography. Circulation, 2001, **103**: 2535–2538.
8) Sato Y, Kanmatsuse K, Inoue F et al: Noninvasive coronary artery imaging by multislice spiral computed tomography: A novel approach for a retrospectively ECG-gated reconstruction technique. Circ J, 2003, **67**: 107–111.
9) Schroeder S, Kopp AF, Baumbach A et al: Noninvasive detection and evaluation of atherosclerotic coronary plaques with multislice computed tomography. J Am Coll Cardiol, 2001, **37**: 1430–1435.
10) Vogl TJ, Abolmaali ND, Diebold T et al: Techniques for the detection of coronary atherosclerosis: Multi-detector row CT coronary angiography. Radiology, 2002, **223**: 212–220.
11) Sato Y, Matsumoto N, Kato M et al: Noninvasive assessment of coronary artery disease by multislice spiral computed tomography using a new retrospectively ECG-gated image reconstruction technique. Circ J, 2003, **67**: 401–405.
12) Sato Y, Imazeki T, Inoue F et al: Detection of atherosclerotic coronary artery plaques by means of multislice spiral computed tomography in patients with acute coronary syndrome: Report of 2 cases. Circ J, 2004, **68**: 263–266.
13) Sato Y, Kato M, Inoue F et al: Detection of coronary artery aneurysms, stenoses and occlusions by multislice spiral computed tomography in adolescents with Kawasaki disease. Circ J, 2003, **67**: 427–430.
14) Sato Y, Matsumoto N, Inoue F et al: Assessment of coronary artery abnormalities in a patient with Kawasaki disease by multislice computed tomography. Heart Vessels, 2004, **19** (in press).
15) Sato Y, Mitsui M, Takahashi H et al: A giant left circumflex coronary artery-right atrium arteriovenous fistula detected by multislice spiral computed tomography. Heart Vessels, 2004, **19**: 55–56.