Coronary Computed Tomography Angiography—A Promising Imaging Modality in Diagnosing Coronary Artery Disease

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Background: Traditionally, information on coronary artery lesions is obtained from invasive coronary angiography (CAG). The clinical applicability and diagnostic performance of the newly developed 64-slice multislice computed tomography (MSCT) scanner in coronary angiographic evaluation is not well evaluated.

Methods: Coronary computed tomography angiography (CCTA) was performed in 345 patients (119 women, 226 men; mean age, 59.64 ± 11.67 years). Concomitant CAG was performed in 53 patients. The diagnostic performance of CCTA for detecting significant lesions was compared with that of CAG by 3 independent cardiologists.

Results: All CCTA was performed without complication. Comparison between CCTA and CAG was made in the 53 patients who underwent both studies. Sensitivity, specificity and the positive and negative predictive values for the 53 patients were: 81%, 99%, 87% and 99%, respectively.

Conclusion: The 64-slice MSCT, developed in recent years, allows reliable noninvasive evaluation of coronary artery morphology, including plaque, stenosis and congenital anomaly. The diagnostic accuracy of MSCT scans for detecting lesions makes it a good imaging substitute for CAG in the evaluation of these coronary segments. [*J Chin Med Assoc* 2008;71(5):241–246]

Key Words: coronary artery stenosis, coronary computed tomography angiography, multislice computed tomography

Introduction

Coronary angiography (CAG) is widely accepted as the current gold standard for the assessment of coronary artery stenoses and the performance of percutaneous coronary intervention (PCI).[1–4] High economic cost and the invasiveness of CAG have made multislice computed tomography (MSCT) an alternative modality for the diagnosis of coronary artery disease (CAD).[5,6] The MSCT procedure is safe and well tolerated by most patients.[7] The high negative predictive rate is useful in selecting the patients who need further CAG and PCI.[2,3,8] It is particularly useful when patients present with atypical chest pain and equivocal results on other functional noninvasive screening tests.[4,6]

Methods

Study population

A total of 345 patients (119 women, 226 men; mean age, 59.64 ± 11.67 years) underwent MSCT between July 2005 and December 2006. CAG was performed either before or after MSCT. The study population included patients with atypical chest pain, asymptomatic self-referred patients, patients who were unwilling to undergo CAG, or patients who were suspected

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of having congenital coronary artery anomaly but not diagnosed with CAG. The ethics committee of the hospital approved the trial, and all patients gave written informed consent.

Patients with elevated or irregular heart rate were given a beta-blocker (inderal 10 or 20 mg orally) until their heart rate decreased to < 70 bpm if possible. Only 29 patients (8.4%) took beta-blocker prior to CCTA. However, in patients in whom beta-blocker usage was contraindicated or if the lowering of the heart rate was not sufficient, the scan was performed even when the heart rate remained high.

Scan protocol

All 345 CT scans were obtained on a 64-slice scanner with a 0.35-second rotation time (VCT; GE Healthcare). An initial non-enhanced electrocardiographic (ECG)-gated scan was performed for calcium scoring (8 × 2.5-mm collimation, tube voltage 120 kV, tube current 320 mA). A bolus of 80 mL of contrast medium (Omnipaque 350 mg/mL or Visipaque 320 mg/mL; GE Healthcare, Ireland) was injected into an antecubital vein at a flow rate of 5 mL/s, followed by a 50-mL saline chasing bolus. The injection was coupled to the image acquisition using SmartPrep software. Start delay was defined in the ascending aorta and scan start was automatically initiated 5 seconds after the threshold (140 HU) was reached. Scanning was then performed from tracheal bifurcation to the diaphragm. The scanning parameters were as follows: X-ray tube potential 120 kV, effective tube current modulated 500–700 mA (maximal 700 mA), slice 0.625-mm helical thickness, 40-mm detector coverage, 0.35-second gantry rotation time.

Image processing and data analysis

The total calcium score was quantified by specific software (SmartScore), according to a scoring system originally developed by Agatson for electron-beam tomography.[9,10] The Agatson score is a commonly used method that calculates the total amount of calcium on the basis of the number, area, and peak Hounsfield units of the detected calcified plaques. All reconstructed images were transferred to a workstation (Advantage 4.2, GE Healthcare). A stack of approximately 1,500–2,500 transverse CT sections were available per patient. Retrospective ECG gating was used for optimal heart phase selection. Retrospective ECG-gated reconstruction was obtained from 5% to 95% of the R-R interval in 10% increments. For each individual artery, the data set with fewest motion artifacts was used for evaluation. CCTA was analyzed on the basis of cross-sectional images, including several post-processing techniques: maximum intensity projection (MIP), advanced vessel analysis (AVA), curved multiplanar reconstruction (MPR) and volume rendering (VR).[11,12]

CAG

Fifty-three patients underwent CAG before or after CCTA. CAG was performed according to standard techniques and evaluated by quantitative coronary analysis (GE Healthcare, Innova 2000). The angiograms were evaluated by 3 experienced cardiologists without knowledge of the MSCT coronary angiographic findings. The coronary arteries were segmented according to the guidelines of the American Heart Association and a previous publication[13] as follows: right coronary artery (RCA): 1, proximal; 2, mid; 3, distal; 4, posterior descending; left main coronary artery (LM): 5; left anterior descending artery (LAD): 6, proximal; 7, mid; 8, distal; 9, diagonal 1; 10, diagonal 2; left circumflex artery (LCx): 11, proximal; 12, first marginal; 13, distal; 14, second marginal; 15 posterior descending.[13] The posterior descending artery was considered as independently defined when originating from the RCA (segment 4) or LCx (segment 15). A reduction in diameter of > 50% was defined as significant stenosis.

Statistical analysis

The diagnostic performance of CCTA for the detection of significant coronary artery stenosis with CAG as the standard of reference was presented as sensitivity, specificity, positive and negative predictive values. Comparison between CCTA and CAG was performed on 2 levels, segment by segment, and vessel by vessel. Continuous data were expressed as mean ± standard deviation. Differences in continuous variables were analyzed using the unpaired Student's *t* test.

Results

All 345 CCTA were performed without complications. Patient characteristics are shown in Table 1; 46.1% of patient had hyperlipidemia, 40.9% had hypertension, 14.2% had smoking history, 16.5% had diabetes mellitus, 45.8% were ≥ 60 years old, and 33.9% had calcium score > 400.

As shown in Table 2, 75 (21.7%) patients had myocardial bridge (most in the LAD and only 2 in the LCx). Fifteen (4.3%) had congenital anomaly, and 68 (19.7%) had occlusive CAD (> 50% stenosis). About 46% of patients had abnormal findings. In Table 3, we compare the detection rates of myocardial

Table 1. Patient characteristics and risk factors*

Mean age (yr)	59.64 ± 11.67
Age ≥ 60 yr	158 (45.8)
Male sex	228 (66.1)
Hyperlipidemia	159 (46.1)
Hypertension	141 (40.9)
Smoking	49 (14.2)
Calcium score > 400	117 (33.9)
Diabetes mellitus	57 (16.5)

Data presented as mean ± standard deviation or n (%).

Table 2. Abnormal findings on coronary computed tomography angiography in the 345 patients

Abnormal finding	*n* (%)
Myocardial bridge	75 (21.7) [LAD, 73; LCx, 2]
Congenital anomaly	15 (4.3)
RCA from LCC	5
High takeoff	7
Fistula	1
Single coronary artery – 1 RCA from LM, 1 RCA from LCx	1
Occlusive CAD	68 (19.7)
Others	8 (2)
Lung cancer	3
Aortic dissection	3
Pulmonary embolism	1
Hiatal hernia	1

LAD = left anterior descending artery; LCx = left circumflex artery; RCA = right coronary artery; LCC = left coronary cuspid; LM = left main coronary artery; CAD = coronary artery disease.

bridge and congenital anomaly as detected by CCTA and CAG.

Mismatched lesions with significant stenoses on CCTA but negative on CAG were mostly due to heavy calcification. The negative lesions on CCTA that showed significant stenoses on CAG were due to small lumen diameter or motion artifacts. The RCA was most frequently affected by degraded image quality. In the evaluable arteries, all occlusions and high grade stenoses (> 50% stenoses) in vessel segments with a diameter > 2.0 mm were correctly detected by MSCT. But stenoses in vessel segments < 2.0 mm in diameter failed to be detected. Other factors for lesion mismatch included stent with strong metallic artifact, positive remodeling of coronary artery segment with > 50% stenosis in CCTA but not in CAG.

Of the 345 patients, 53 had received CAG study before or after CCTA study; 43 patients revealed abnormal findings. In total, 795 segments (53 × 15) were included for comparison with CAG, although no patients had stenosis over segment 15. The diagnostic performance of CCTA for detecting significant lesions on a segment-based analysis is detailed in Table 4. In the 795 evaluable arteries, a total of 84 stenoses were detected on CAG and 71 stenoses were correctly detected by MSCT. Twenty-two of 25 lesions in the RCA, 5 of 5 in the LM, 31 of 40 in the LAD and diagonal branches, and 13 of 29 in the LCx were correctly identified. All 8 false-negative stenoses were in the distal RCA, posterior descending artery, diagonal branches and obtuse marginal branches. In 711 of 795 coronary arteries, the absence of occlusive CAD was correctly detected. Nine cases of occlusive CAD were falsely diagnosed. These values corresponded to a sensitivity of 81%, specificity of 99%, positive predictive value of 87%, and negative predictive value of 99% for the detection of high-grade coronary artery stenoses by MSCT.

Table 3. Comparison of myocardial bridge and congenital anomaly detected by coronary computed tomography angiography (CCTA) and coronary angiography (CAG) in 53 patients

	CCTA	CAG
Myocardial bridge	16	4
Congenital anomaly		
RCA from LCC	2	1
High takeoff	2	1
Fistula	1	1
Single coronary artery (RCA from LCx)	1	1

RCA = right coronary artery; LCC = left coronary cuspid; LCx = left circumflex artery.

Discussion

The high negative predictive value of CCTA has been widely discussed in the literature,[7,14–16] and there has been improvement in diagnostic accuracy from 16-slice CT to 64-slice CT.[17–19] The high negative predictive value of 99% in this study indicates that CCTA should be given a more prominent role in the diagnosis of coronary artery stenoses in patients whose symptoms or abnormal stress test results make it necessary to rule out the presence of coronary stenoses.[18,20] CCTA is useful to facilitate early and accurate discharge of patients with acute chest pain.[7,17] The absence of coronary artery plaque or stenoses on CCTA has a high negative predictive value in the subsequent diagnosis of acute coronary

Table 4. Diagnostic accuracy of 64-slice coronary computed tomography angiography for detecting significant stenoses in coronary arteries

	RCA	1	2	3	4	LM	LAD	6	7	8	9	10	LCx	11	12	13	14	15	Total
> 50% stenosis on CAG		6	3	7	3	5		5	14	7	5	4		10	2	2	1	0	84
Sensitivity (%)	85	86	100	86	67	100	90	71	93	87	100	100	63	100	50	100	0		81
Specificity (%)	99	98	100	100	100	100	98	96	97	98	100	100	98	98	96	98	100		99
PPV (%)	97	86	100	100	100	100	90	71	93	88	100	100	64	91	33	67	–		87
NPV (%)	99	100	100	98	98	100	98	100	100	100	96	96	99	100	98	100	98		99
Accuracy		98	100	98	98	100		96	98	98	96	96		98	94	98	98		98
TP		6	3	6	2	5		5	14	7	3	2		10	1	2	0		71
FP		1	0	0	0	0		2	1	1	0	0		1	2	1	0		9
TN		46	50	46	50	48		46	37	45	48	49		42	49	50	52	53	707
FN		0	0	1	1	0		0	0	0	2	2		0	1	0	1		8

RCA = right coronary artery; LM = left main coronary artery; LAD = left anterior descending artery; LCx = left circumflex artery; CAG = coronary angiography; PPV = positive predictive value; NPV = negative predictive value; TP = true positive; FP = false positive; TN = true negative; FN = false negative.

syndrome. It can provide incremental information for clinical risk assessment among patients who present with acute chest pain to the emergency room. In our study, causes of chest pain other than CAD, such as intramural hematoma of the ascending aorta, aortic dissection, lung cancer, pulmonary embolism, or hiatal hernia, were found in those patients who underwent CCTA only. In cases of intramural hematoma of the ascending aorta and aortic dissection, CAG study might be risky, and under such circumstances, CCTA would be a good substitute for the screening of CAD. Thus, CCTA can be more acceptable as a screening procedure for atypical chest pain.

It is reported that motion artifacts and severe coronary calcification are 2 major limitations in coronary artery stenosis interpretation.[15,21–23] High heart rates decrease image quality, so we tried to decrease heart rate to < 70 bpm. To reduce the number of respiratory motion artifacts, every patient received instructions in respiration control in trial runs, before the actual examination, to ensure that their breath-holding would be adequate during image acquisition. Owing to improvement in scanning from 16-slice to 64-slice, there was an acquisition time of 5–6 seconds to obtain 64 × 0.625-mm MSCT scans. The breath-hold time of 5–6 seconds was acceptable to most patients; even patients with chronic obstructive pulmonary disease could tolerate such a short breath-hold time. However, motion artifacts were still present, mostly in the RCA and LCx.

Calcium score was routinely calculated for every patient in this study. A previous study revealed a modest increase in the risk of new cardiovascular events associated with coronary artery calcium deposits in asymptomatic persons.[24] Over- or underestimation of the severity of coronary artery stenoses by the presence of coronary calcium is still a hard problem to overcome.[3,21,25] Eight mismatchings (15%) were due to heavy calcification. Heavy or circular calcification causes beam hardening artifact, making lumen diameter evaluation difficult. It has been suggested that CAG study should be recommended for patients with high calcium score.[22] High calcium scores do impair analysis of lumen stenosis, but coronary calcification should not be used as an indication for deferring CCTA because calcium score does not always significantly impair the overall diagnostic accuracy of CCTA for stenosis evaluation.[24]

Congenital coronary artery anomalies are rare but potentially lethal.[26–28] They may lead to angina, ischemia or infarction. Traditionally, coronary anomalies have been detected by CAG, but accurate diagnosis is sometimes difficult. The spatial relationship of the anomalous coronary artery and adjacent structures cannot be thoroughly evaluated using CAG. The proximal course of the anomalous coronary arteries is very important in decision-making for surgical correction. MSCT can reveal the structure of surrounding myocardium. It provides myocardial bridging information regarding the length, depth, precise location and presence or absence of atherosclerosis. CCTA has been proposed as the new gold standard for the evaluation of coronary artery anomalies.[26]

The results obtained in this study encourage further research on CCTA, but high heart rates and arrhythmia are still problems to overcome. How heavy calcified plaque can be removed from coronary artery walls so as not to impair stenosis evaluation is still a problem that needs to be resolved. In addition to anatomic information, MSCT needs to provide more functional information as a substitute for examination before percutaneous transluminal coronary angioplasty or coronary artery bypass graft.

In conclusion, noninvasive 64-slice MSCT demonstrates good diagnostic performance in the detection of coronary artery stenoses in patients with atypical chest pain or possible myocardial ischemia. However, dedicated software tools to reduce motion artifacts and the influence of heavy calcification may help to further increase its sensitivity and positive predictive value. This noninvasive technique may be a good imaging substitute for CAG.

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