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NON-INVASIVE ANGIOGRAPHY

Original Studies

Clinical Utility of Coronary CT Angiography: Coronary Stenosis Detection and Prognosis in Ambulatory Patients

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Introduction: Multislice CT coronary angiography (MSCTA) accurately detects stenosis in patients undergoing coronary arteriography, but its accuracy in clinical outpatients is less certain. This study retrospectively analyzed MSCTA performance in a large outpatient cohort and examined 6-month clinical follow-up in those without invasive CA. Methods: Patients underwent MSCTA for clinical indications including symptoms or noninvasive results being either equivocal or suspected as incorrect by referring clinicians. Standard 16-slice CT scanner techniques were used, and results were analyzed on the basis of both patient and vessel. Patients were treated medically or sent to invasive angiography on the basis of MSCTA results and judgment of referring clinicians. All invasive angiograms were analyzed using quantitative coronary angiography. Six-month clinical follow-up was determined in patients without CA. Results: One thousand fifty-three consecutive patients were referred for MSCTA, resulting in 994 interpretable scans. Mean age was 58 ± 13 years, 55% were male, 50% had prior noninvasive testing, and 90% had symptoms. Invasive angiography was performed in 160 patients, with significant stenoses present in 69%. MSCTA demonstrated 87% and 89% accuracy by patient- and vessel-based analysis, respectively, and was most accurate in the left main and right coronary arteries. Only two patients not referred for angiography had signficant stenosis in those undergoing 6-month follow-up. Conclusions: MSCTA accurately detects obstructive coronary stenosis in clinical patients with possible cardiac symptoms, and effectively triages them for invasive angiography. Negative results are highly accurate in ruling out obstructive disease. Six-month prognosis is excellent in patients without significant disease determined by MSCT. © 2006 Wiley-Liss, Inc.

Key words: multislice CTA; coronary stenosis; atherosclerosis

INTRODUCTION

Coronary angiography using multislice CT (MSCTA) is emerging as an important noninvasive examination capable of imaging both the coronary artery lumen and wall. No data yet exist for coronary MSCTA in clinically referred populations with unknown coronary artery disease status, since prior studies were performed in populations already selected for coronary arteriography. In this study, we evaluated MSCTA to characterize its performance in patients referred for clinical indications.

Spatial and temporal resolutions of CT technology are associated with less than 12% unreadable coronary artery segments [1–3]. However, spatial and temporal resolutions remain inferior to invasive coronary angiography [4,5]. Studies of coronary CT angiography in

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patients scheduled for invasive coronary angiography show that MSCTA compares favorably with invasive coronary angiography. Sensitivity is about 92% and specificity is 95% for detecting obstructive disease, while positive and negative predictive values are about 79% and 98%, respectively [2,3,6–9]. These studies were limited by relatively small numbers of selected patients. MSCTA in patients with a high pretest probability of coronary artery disease has a reduced negative predictive value of 75% per patient [6].

METHODS

Study Population

This retrospective study analyzed consecutive patients undergoing coronary MSCTA during a 14-month period (September 2003 through December 2004). Patients were referred for MSCTA by experienced cardiovascular clinicians for clinical indications regarding coronary artery status. Referral indications were most often chest pain or shortness of breath. Many patients were also referred after other noninvasive tests had been performed.

All patients undergoing MSCTA gave informed consent and were included in a registry approved by the Institutional Review Board. Patients with prior stent placement or bypass surgery were included in the study, since they had been referred to evaluate the possibility of new disease as a cause of symptoms or equivocal stress testing. Patients were excluded from scanning for any of the following: history of contrast allergy with inadequate premedication, active wheezing present, heart rate ≥65 bpm, unable to perform breath-hold for at least 20 sec, atrial fibrillation, or coronary calcium score ≥1,900. The choice of 1,900 for calcification limit was chosen empirically after examining multiple cases early in the MSCTA experience, where calcification was too dense to adequately visualize the coronary lumen.

Scan Technique and Image Evaluation

The scan technique is detailed in Appendix 1. One reader (JRL) evaluated all images on one of two off-line workstations (Siemens Leonardo and/or Vitrea 2, Vital Images, Minnesota, MN). Coronary vessels ≥2 mm were visually assessed for stenosis severity, and considered significant if visually ≥50% diameter. The reader was unblinded to clinical information. The decision for proceeding to invasive coronary angiography was made by the referring cardiologist, with clinical data including knowledge of the MSCTA result.

Coronary Calcium Score

Coronary calcium scoring was performed on all patients who (1) had no previous score, and (2) had no prior coronary artery bypass surgery or stent placement. Details are in Appendix 1. Severe coronary calcification was defined as a calcium score ≥1,900 for reasons described earlier.

Invasive Coronary Angiography

Referral to invasive coronary angiography after MSCTA was made by the patient's clinician, who had initially referred the patient to MSCTA. Invasive study was based on individual clinical judgment including symptoms, noninvasive results, and MSCTA result.

Diagnostic invasive coronary angiography was performed using standard methods. Each invasive coronary angiogram was retrospectively analyzed using standard quantitative coronary angiographic (QCA) methods with a commercial system (General Electric Medical Systems). This analysis was performed without knowledge of the MSCTA result.

Correlation of MSCTA and Invasive Coronary Angiography

All patients undergoing coronary MSCTA and invasive coronary angiography were evaluated using both patient- and vessel-based analysis as follows.

Patient- and vessel-based analysis. MSCTA results were classified as true/false positive or true/false negative using a visual diameter stenosis estimate of ≥50%. Invasive coronary QCA was positive if any diameter stenosis ≥50% was found anywhere in the coronary tree in vessels 2 mm or more in diameter.

For vessel-based analysis, four anatomic artery categories were created: left main, left anterior descending, circumflex, and right coronary arteries, and included all branches of each territory. MSCTA visual analysis was compared with invasive QCA results for each anatomic location. In vascular territories supplied by a bypass graft, a lesion was classified as significant if invasive QCA showed a stenosis ≥50% in a vessel with no unobstructed graft supplying it. Vascular territories with significant native lesions and patent bypass grafts were not considered as significant stenoses.

Vessel segments uninterpretable by MSCTA (due to excessive coronary motion, severe calcification, or slice misregistration) were conservatively classified as inaccurate, since lesion severity could not be assessed. Such results were false positive or false negative depending upon the invasive angiographic QCA result.

Patient follow-up. Patients were eligible for follow-up if a minimum of 6 months had elapsed after MSCTA scan. Patients who did not undergo invasive coronary angiography were contacted by telephone or mail at least 6 months after their scan, and asked a standardized set of follow-up questions. These questions obtained information about intervening stress test-

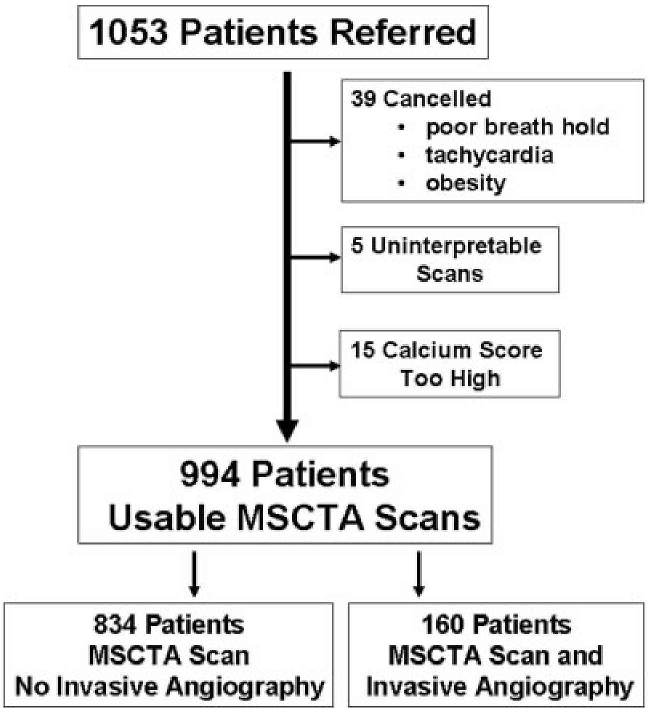

Fig. 1. Flow chart for numbers of patients referred for Multidetector CTA scanning.

ing, hospitalizations for all cardiac causes, invasive coronary angiography, and cardiac events including myocardial infarction, and/or cardiac death. The individual obtaining follow-up was not aware of MSCTA results. Each positive response was followed by medical record review including subsequent coronary angiogram, if available. Patients not available by telephone were sent the questionnaire by mail.

RESULTS

Patient Referral, Scanning, and Demographic Information

One thousand fifty-three (1,053) consecutive patients referred for MSCTA were reviewed to obtain 994 usable scans (details in Fig. 1). Table I shows heart rate and complication data for the scans. Demographic information for the 994 patients with interpretable scans is shown in Table II. Referral indications and patient selection are shown in Table III.

Calcification and Outcome based on Referral to Invasive Angiography

Calcium score was available in 793 of the 994 patients, with usable scans. The mean (±SD) calcium score in this overall group was 215 ± 485. In 87 patients from this group, calcium scoring was not performed because of known prior disease, but was visually interpreted as "high" in 79 patients, and "mild" or "modest" in 8. Calcium score was not available in 114 patients. Thirteen patients had invasive coronary angiography recommended after a markedly elevated calcium score was found during the calcium scoring prior to MSCTA. In each of these 13 cases, MSCTA was cancelled, and invasive angiography revealed significant disease in 10 of these 13 patients (77%).

Mean calcium scores were calculated in the subgroup of patients referred for invasive coronary angiography. There were 160 patients in this group, and the mean calcium score was 471 ± 175 (available in 109 patients), recorded as high in 21, modest in 2, and not available in 28. The calcium scores for patients not referred for coronary arteriography were 174 ± 473

TABLE I. MSCTA Heart Rate (HR) Information for Scans

Parameter	Value	Range
Initial HR (mean)	67	46–100
HR during Scan (mean)	56	36–120
Received Oral Beta Blocker per protocol	654/1033 (63)	
Received oral and intravenous beta-blocker per protocol	192/644 (30)	
Received intravenous beta-blocker alone	40/1033 (4)	
Achieved Goal Heart Rate ≤65 bpm	942/1033 (91)	
Complications from beta blockade	2/1033 (0.2)	
1 patient, syncope from bradycardia, 40 bpm		
1 patient, severe bradycardia alone, 36 bpm		

Values given in parenthesis are percentages.

TABLE II. Demographic Data, All Patients with Usable MSCTA Scan ($n = 994$)

	Patients	%
Age (years ± SD)	58.5 ± 12.8	
Medicare age (≥65 years)	343/994	35
Gender		
Male	556/994	55
Female	453/994	45
Symptomatic	912/994	92
Prior stress testing with or without stress imaging	507/994	51
Prior Intervention	158/994	16
CABG alone	59/158	37
PCI with or without CABG	99/158	63
Risk Factors (Patients)[a]		
0	49/994	5
1	119/994	12
2	284/994	29
3	274/994	28
≥4	242/994	24
Not Available	41/994	4
Patients ≥6 months after CTA and no invasive coronary angiography	554/994	56

[a]Risk factors include diabetes, history of or currently smoking, hypertension diagnosis or treatment, hyperlipidemia diagnosis or treatment, known coronary artery disease, and family history of coronary artery disease.

TABLE III. MSCTA Referral Indications ($n = 994$)

Chest pain or dyspnea suspected as an anginal equivalent	912/994	92%
Suspected unreliable stress test result	496/994	50%
Chest pain or dyspnea with no recent stress test	513/994	52%
Suspected unreliable stress test result without symptoms	35/994	3.5%
No symptoms and no stress test within 3 months (complicated prevention decision)	42/994	4.2%
Known cardiomyopathy: evaluate coronary arteries for possible atherosclerosis	19/994	1.9%
Evaluate for possible coronary artery anomaly	8/994	0.8%
Pre-operative coronary artery evaluation for possible atherosclerosis	4/994	0.4%
Known left main coronary stent or coronary artery aneurysm, evaluate lesion	8/994	0.8%

Note: A single patient may appear in one or more categories.

(681 patients with score available), high in 61, mild or modest in 6, and not available in 86.

MSCTA Test Performance Compared With QCA: Patient- and Vessel-Based Analyses

MSCTA was assessed by both patient- and vessel-based analysis using invasive QCA results for comparison. Patient-based results are shown in Table IV, and case examples are shown in Figs. 2 and 3. Excellent true positive and negative percents were noted, 86% and 91%, respectively.

Vessel-based MSCTA performance analysis was subdivided into all-vessels (Table V) and per-vessel analysis (Table IV). The all-vessel data show true positive and negative percents to be 78% and 94%, respectively. Per-vessel data show MSCTA had the highest true positives in the right coronary artery (89%) and the most true negatives in the left main (99%).

Patient Follow-Up

Telephone interview was attempted in the 554 eligible patients (Fig. 4) with at least 6 months elapsing after MSCTA and no invasive angiography recommended. Determination of events was carried out without the knowledge of MSCTA result. Only 1% (5 of 554) of these patients could not be located by telephone, review of medical records, or by mailed questionnaire. In this 5-patient group without follow-up, the mean age was 45, and mean calcium score was 24. The 549-patient follow-up group was thus composed of those in whom at least 6 months had elapsed from scan, while the remaining MSCTA-only were those who had not reached the 6-month follow-up point.

In the 549 patient full-follow-up patient group, none suffered myocardial infarction or death. Fifty patients were hospitalized or visited an emergency department, and 14 of these were determined to have had noncardiac chest pain or noncardiac conditions. Three additional patients had negative stress tests during hospitalization. Thirty-three had invasive angiography, and 31 of these 33 had no significant coronary artery disease (disease <50% stenosis). Eleven additional patients had outpatient stress tests, all of which were negative for ischemia.

TABLE IV. MSCTA Scan Accuracy: Patient-Based Analysis

	MSCTA Scan Results		
	Positive	Negative	Total
QCA Positive	108 (86)	3	111
QCA Negative	18	31 (91)	49
Total	126	34	160

Values given in parenthesis are percentages.

An additional 85 unselected patients were contacted after a mean of 402 $\pm$ 60 days from MSCTA scan. In this subset, there was only one coronary event, a patient who required two stents placed electively. There were four patients with noncoronary artery related events: one patient with pacemaker placement, one patient who had diagnostic angiography showing mild/nonobstructive disease, one patient with carotid stent placement, and one patient with a "slight stroke."

DISCUSSION

This study evaluated MSCTA in a cohort of selected outpatients. The patient population was unique, differing from prior MSCTA studies, since patients were referred from outpatient clinics with atypical symptoms and uncertainty about coronary artery disease. Only 16% (160/994) were sent for invasive coronary angiography. Earlier MSCTA studies examined patients already selected for coronary angiography for clinical reasons [2,3,6,8–10].

MSCTA and Invasive Coronary Angiography

The invasive angiographic population for comparison was smaller, and MSCTA performed well in those patients. The only loss of performance was a specificity of 63%, somewhat less than 87%, reported by Ropers et al. [3], resulting in an MSCTA positive predictive value of 86%. Several factors may explain this result. We did not exclude unreadable arteries, but considered them as inaccurate results, leading to a decreased sensitivity and specificity. Although the spatial resolution of the 16-row MSCT is submillimeter, it is still inadequate to prevent partial volume averaging of calcium, the most common cause of false positive readings [6,11]. The through-plane (z-axis) spatial resolution (0.6 mm) does not allow discrimination of diameter stenosis to within 20% [5]. This places more

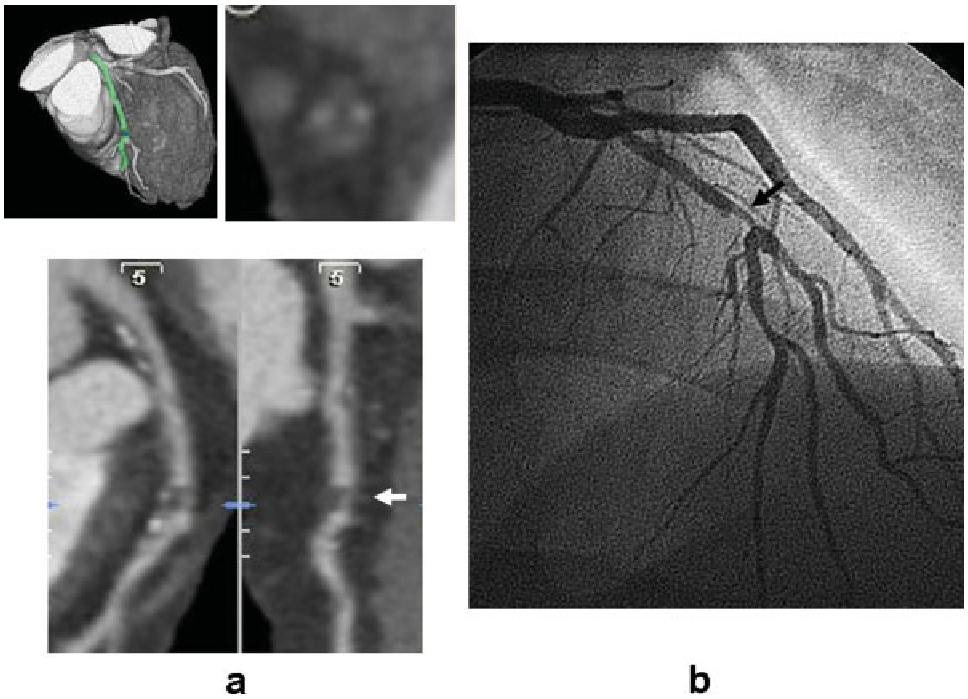

Fig. 2. (a) Volume reconstruction technique (VRT), and orthogonal sections showing the left anterior descending coronary artery. There is a severe stenosis in the mid-portion of this vessel consisting of both calcified and uncalcified components, though much of the atherosclerosis in this patient is calcified plaque (black arrow). (b) Same patient with similar layout of the left circumflex coronary artery. Similarly visualized is a severe stenosis of the proximal coronary artery, with calcified and uncalcified plaque (black arrow). (c) Still frame from an LAO projection of the invasive coronary angiogram showing both the LAD and Circumflex lesions corresponding to those seen on the MSCTA scan. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

lesions in an indeterminate category and subject to overestimation. Voluminous plaque and suboptimal resolution also make accurate lesion quantitation difficult, which may make an apparent stenosis in a coronary artery that was not found by QCA, which cannot image mural plaque. Despite aggressive beta-blockade, the limited temporal resolution and 20-sec breath hold necessary for 16-row MSCTA occasionally caused motion and slice misregistration artifacts that interfered with analysis [12].

Invasive QCA also has problems, limited by its lack of 3D information with vessel overlap and limited view availability. The need to find “normal” reference vessel locations in patients with diffuse atherosclerotic remodeling (abluminal vessel enlargement and narrowing) may also yield inaccurate information regarding anatomic and presumed physiologic importance of a stenosis [13,14].

MSCTA in this population was comparable to prior studies of patients already selected for coronary angiography, and thus suspected of having obstructive coronary artery disease. Similar to prior studies, the value of a negative MSCTA scan is accurate (94%) for vessel based analyses. The lack of cardiac events and the small number subsequently discovered with significant disease by follow-up also suggest that a negative test appropriately identified patients who could avoid invasive angiography.

When analyzed on a per-vessel method, MSCTA performance was only mildly degraded. In the patient-based analysis, if a scan was positive in any coronary artery for severe stenosis by MSCTA, and if a significant stenotic lesion was found anywhere on the invasive coronary angiogram, this was considered a true positive. In the vessel-based analysis, the same MSCTA scan comparison was made except on a vessel-by-vessel lesion location analysis.

Using the vessel based analysis, MSCTA was accurate for detecting and ruling out left main and right coronary artery disease. Reasons for differences by vessel imaged are uncertain, but may relate to vessel size. The left main and right coronary arteries are typically larger than the left anterior descending and circumflex, both of which demonstrated mildly decreased accuracy for MSCTA lesion detection. The errors in left anterior descending and circumflex artery detection are principally false positive tests, occurring when large plaque volume and calcified plaque is visualized,

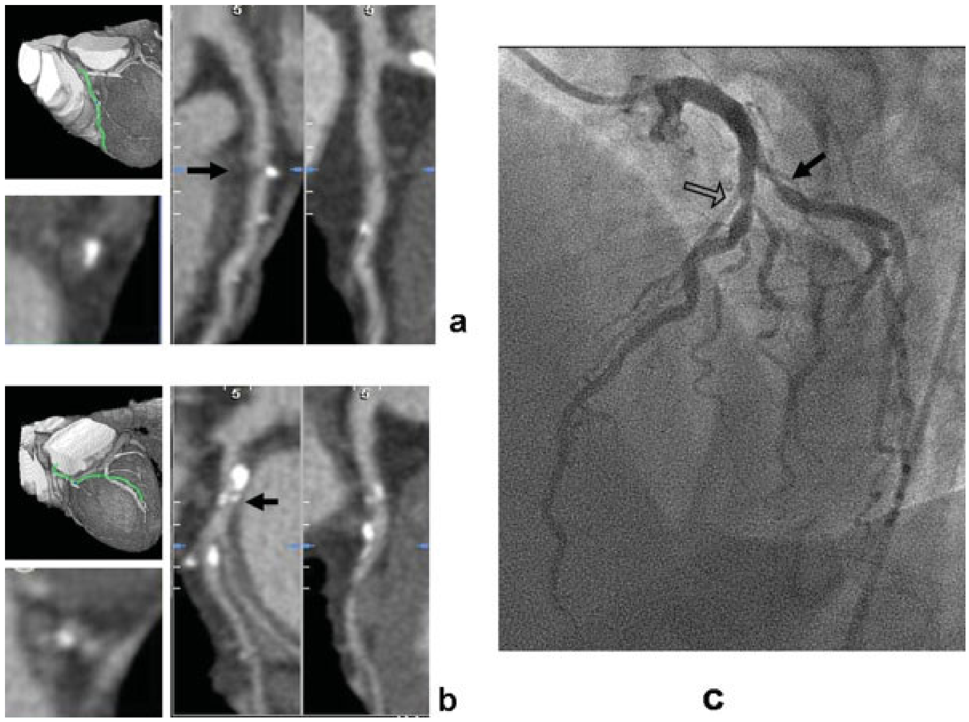

Fig. 3. (a) Volume Reconstruction Technique (VRT), and orthogonal sections showing a stenosis of the left anterior descending coronary artery. The plaque causing this stenosis has minimal calcification (black arrow). Note that much of the plaque in this patient is uncalcified.(b) Still frame from an LAO projection of the invasive coronary angiogram showing a very discrete, severe stenosis of the proximal LAD corresponding to that seen on the MSCTA scan. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

TABLE V. MSCTA Scan Results: Vessel-Based Analysis (Disease Prevalence 69%)

	CTA Scan Results		
	Positive	Negative	Total
QCA Positive	140 (78)	29	169
QCA Negative	40	423 (94)	463
Total	180	452	632

Values given in parenthesis are percentages.All vessels with lesions of uncertain severity because of heavy calcification, motion, or marked slice misregistration, were considered to be inaccurately interpreted by CTA. These represented either a false positive or false negative vessel based upon the invasive angiographic QCA results.

TABLE VI. MSCTA Performance (Vessel-Based): Summary

	Overall	Left Main	LAD	Circumflex	Right
Percent True Positive	78%	75%	74%	72%	89%
Percent True Negative	94%	99%	90%	91%	92%

with its impact on the vessel lumen unable to be accurately determined because of limited resolution. The negative predictive value of a scan is high. MSCTA is effective in ruling out obstructive coronary artery disease in the LAD and LCX vessels.

Selection bias against invasive coronary angiography likely skewed results in this study. We performed an additional analysis using the 834 patients who had negative scans and so did not receive invasive study. Of these patients, we estimated that 831 were normal, based on extrapolation as follows. Of 554 patients with 6-month follow-up, two were found with $\geq$50% stenosis, and applying this ratio (2/554) to the 834 patient group yields about three with disease, or 831 that were normal. Recalculation of sensitivity and specificity based on this simple extrapolation yields 95% (108/114) and 98% (862/880), respectively. These values are similar to those from prior literature of patients already scheduled for invasive study before having CTA.

These findings support using MSCTA if obstructive coronary atherosclerosis is suspected in a patient with symptoms. The obstructive disease prevalence by QCA was lower than many comparable series (69%), likely degrading noninvasive stress test performance, since positive predictive value is proportional to disease prevalence. This study validates MSCTA as useful for detecting coronary atherosclerosis in patients with typical and atypical symptoms. New scanners using 64-detector technology will further refine spatial resolution and likely improve the ability to delineate coronary artery plaque and resulting stenosis.

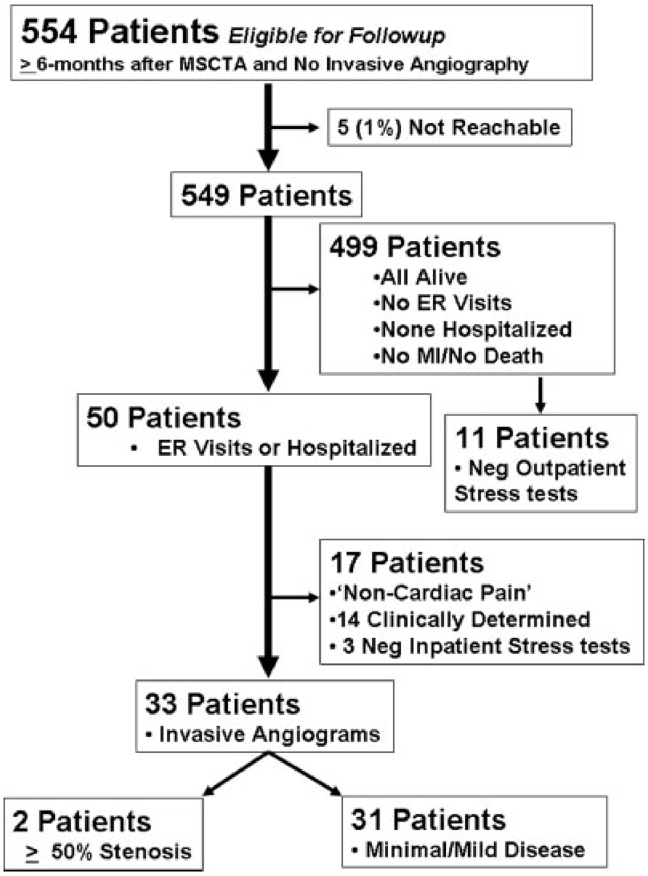

Fig. 4. Flow-chart with patient numbers for long-term follow-up.

A compelling finding of the study was that patients with either no disease or insignificant stenoses by MSCTA have an excellent 6-month prognosis. This information suggests that MSCTA may be applicable for short-term prognostication in outpatients for likelihood of heart attack, hospitalization, or revascularization. Longer-term follow-up and further specific evaluation of coronary plaque will be needed to better establish the utility of MSCTA in determining late risk [15,16].

Limitations

Referral and verification bias. The most significant limitations of this retrospective study are referral and verification bias [17–19]. Referral bias was subjective, since the clinician requesting MSCTA often had an equivocal noninvasive test, or suspected a false positive or false negative result. Referral bias strongly affects sensitivity calculations, and thus, the number of stenoses missed by this study is not unknown for the patients not referred for angiography. The study population was thus rich in false noninvasive testing, and for this reason, "sensitivity" and "specificity" calculations were not performed.

Verification bias was similarly prominent, since patients were preferentially referred to invasive angiography when MSCTA suggested obstructive disease. Referral bias affects sensitivity and specificity calculations, since the MSCTA result itself was affected by the patients who were sent to invasive angiography. Such bias causes significant overestimation of sensitivity, a phenomenon well-known in referral populations. The excellent clinical follow-up results however suggest the validity of our conclusions. One additional limitation is that very high calcification scores remain a significant limitation to MSCTA interpretation, as was true for electron beam CT in the past.

These biases necessitate expressing data as percent true positives and true negatives, reflecting positive and negative predictive values, as used in other studies of CTA accuracy.

Number of detectors: 16 versus 64-detector data. Another potential limitation is the number of detectors. Currently, 64-detector scanners have only recently entered routine clinical practice. The differences between 16- and 64-detector CT technologies are incremental, rather than quantum improvements. CT 64-detector technology typically utilizes 64 detectors with spatial resolution 0.6 mm and tube rotation time 370 msec, compared with 16-detector machines with 16-detectors, 0.75 mm resolution, and tube rotation time 375 msec. A study comparable to the present study but using 64-detector technology would thus likely be an incremental improvement in the current manuscript. The data of this study could only be improved in terms of future conclusions.

Patient follow-up. In this study, 549 patients underwent 6-month follow-up and 85 underwent 12-month follow-up. Although this timeframe is shorter than desirable, the conclusion that short-term prognosis is excellent still stands, and future data with 64-detector scans will be conducted at longer follow-up times. The technology is rapidly evolving making long-term follow-up with a specific scanning technology difficult.

Patient population inhomogeneity. This study is distinctly different from prior CTA studies. Prior studies examined more heterogeneous populations, but highly preselected, since they were undergoing invasive coronary arteriography. The present study represents an unselected sequential cohort, undergoing clinical evaluation for coronary artery disease with atypical symptoms, and often with noninvasive test results that were equivocal or suspected false. This included patients with known coronary artery disease, looking for a specific chest pain etiology.

CONCLUSIONS

There are two principal conclusions of this study. First, if nonobstructive disease is diagnosed by MSCTA, it confers a good prognosis in that 90% (499/554) of such patients did not visit the medical system in at least the following 6 months for chest pain and a very small minority 0.4% (2/554) of those who did had severe coronary disease detected. MSCTA can accurately determine obstructive coronary artery disease in patients referred with a question of coronary artery disease. Many patients had equivocal or clinically suspicious false results on noninvasive testing. MSCTA using 16-detector scanners has excellent accuracy for the left main and right coronary arteries. MSCTA in the left anterior descending or circumflex suffers principally from false positive results. New scanners with 64-detector capability may improve this performance through enhanced spatial and temporal resolution.

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APPENDIX 1: IMAGING AND PATIENT PREPARATION PROCEDURES

Premedication. Patients were given oral metoprolol 50 or 100 mg one hour before scan if the heart rate was 60-64 or >64, respectively. Intravenous metoprolol from 5 to 25 mg total was added at the time of the scan if the heart rate rose above 65 bpm. The scan was cancelled if the heart rate could not be decreased to less than 66 bpm unless it was felt that alternative tests would be inferior despite a potentially compromised image. If absolute contraindications to beta blockade existed (active wheezing, decompensated heart failure) and the heart rate was $\geq$ 65 bpm, the scan was cancelled.

Scanning Technique

A 16-row MSCT scanner (Sensation 16, Siemens, Germany) was used for all scans. For a heart rate of > 50 bpm, the scan parameters included: detector collimation 16×0.75 mm, tube rotation time 375 ms (reconstruction algorithm used data from half gantry rotation allowing a temporal resolution of 188 ms), table feed 3 mm/rotation, tube voltage 120 kV, and tube current 400 to 750 mAs. For patients with a heart rate of <50 bpm, tube rotation time of 420 ms and a table feed of 2.6 mm/rotation were used. A bolus of 100 ml of contrast (Visipaque 320, Amersham Health, Forcheim, UK) was injected into an 18 gauge iv (or 20 if an 18 gauge was not possible) for a scan range including the native coronary arteries. To accommodate the larger scan range in patients with bypass grafts, 120 ml of contrast was used. For patients with a heart rate of <50 bpm or >50 bpm, an injection rate of 4.5 and 5 ml/sec was used, respectively. A dual-head injector (Medrad) allowed a 40 ml saline chaser flush to follow contrast injection. Automated bolus tracking triggered the scanner once a threshold of 100 HU was reached in a region of interest in the proximal ascending aorta. A typical breath hold was 20 to 22 sec for native coronary arteries and 24 to 26 seconds for patients with bypass grafts.

Image Reconstruction

Images were reconstructed using a slice thickness of 1.0 mm in overlapping increments of 0.5 mm to limit slice misregistration. A medium sharp reconstruction kernel (B30f) was typically applied. Patients with stents or heavy calcification had alternative reconstruction using a sharp kernel (B46f). Retrospective EKG gating was applied first to 3 standard reconstructions at 65%, 60%, and 30% of the R-R interval. If coronary motion were present, a preview series showed the coronary location of interest at an interval every 5 ms throughout the cardiac cycle. A new reconstruction was performed at the interval which best limited coronary motion. If ectopy was present, the EKG was reviewed and individual premature beats were edited. If coronary motion was evident, the specific point of data acquisition in diastole was changed with each individual R-R interval to achieve the clearest image. For heart rates >70 bpm, a bi-segmental reconstruction algorithm was applied to reduce the temporal resolution down to a minimum of 105 ms. This algorithm was used if the resultant images were superior.

Methods of Scanning and Image Analysis

Image evaluation. The images were evaluated for slice misregistration using 3 standard projections. The axial and oblique multiplanar reconstruction (MPR) and maximum intensity projection (MIP) views were also used. A volume rendered technique (VRT) was performed and a vessel probe (Vital Images) used to acquire a center-line within each major vessel on the VRT. These images were displayed in orthogonal long-axis views to improve the ability to evaluate calcified arteries.

Calcium score. Calcium score was obtained using a 3 mm collimator, tube rotation time of 420 ms, tube voltage 120 kv, tube current of 130 mA, and prospective EKG gating with tube current modulation in systole. The score was calculated using the Agatston method modified for MSCT.