Original Articles

The Value of Electrocardiography-gated Multi-Slice Computed Tomography in the Evaluation of Patients with Chest Pain

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Abstract

Background: Multi-detector spiral computed tomography with retrospective electrocardiography-gated image reconstruction allows detailed anatomic imaging of the heart, great vessels and coronary arteries in a rapid, available and non-invasive mode.

Objectives: To investigate the spectrum of findings in 32 consecutive patients with chest pain who underwent CT coronary angiogram in order to determine the clinical situations that will benefit most from this new technique.

Methods: Thirty-two patients with chest pain were studied by MDCT using 4 x 1 mm cross-sections, at 500 msec rotation with pitch 1–1.5, intravenous non-ionic contrast agent and a retrospectively ECG-gated reconstruction algorithm. The heart anatomy was evaluated using multi-planar reconstructions in the axial, long and short heart axes planes. Coronary arteries were evaluated using dedicated coronary software and the results were compared to those of conventional coronary angiograms in 12 patients. The patients were divided into four groups according to the indication for the study: group A – patients with high probability for coronary disease; group B – patients after CCA with undetermined diagnosis; group C – patients after cardiac surgery with possible anatomic derangement; and group D – symptomatic patients after coronary artery bypass graft, before considering conventional coronary angiography.

Results: Artifacts caused by coronary motion, heavy calcification and a lumen diameter smaller than 2 mm were the most frequent reasons for non-evaluable arteries. Assessment was satisfactory in 83% of all coronary segments. The overall sensitivity of 50% stenosis was 74% (85% for main vessels) with a specificity of 96%. Overall, the CTCA results were critical for management in 18 patients.

Conclusions: Our preliminary experience suggests that CTCA is a reliable and promising technique for the detection of coronary artery stenosis as well as for a variety of additional cardiac and coronary structural abnormalities.

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Coronary artery disease is the most common cause of morbidity and mortality in developed countries [1]. In 1998, 600,000 deaths caused by coronary artery disease were reported in Europe. Almost half of these patients died without any prior symptoms [2]. Invasive selective coronary angiography is the golden standard for determining the presence, severity and site of coronary artery disease, enabling a variety of immediate therapeutic interventions. Nevertheless, this is an invasive procedure with morbidity (1.5%) and mortality (0.15%) [3]. In Europe in 1995, diagnostic selective coronary angiography was performed in more than 1 million patients but only 28% subsequently underwent percutaneous transluminal coronary angioplasty [1].

Non-invasive CT angiography of the heart has always been a challenge because of the heart's complex and continuous motion. The introduction of multi-detector row CT was the cornerstone of a new era in non-invasive imaging of the heart and coronary arteries. The development of ECG-gated scanning, specially developed reconstruction algorithms and dedicated post-processing techniques, currently enable an accurate high resolution anatomic evaluation of the heart and coronary arteries in all phases of the cardiac cycle with a single acquisition [4–14].

In the present study we investigated the spectrum of findings in 32 patients with chest pain who had undergone CTCA, in order to determine the patient groups that will benefit most from this new non-invasive technique.

Patients and Methods

The study population consisted of 32 consecutive cardiac patients (24 males, 8 females; age range 25–83, mean 59 years) who complained of chest pain and underwent CTCA as part of a general cardiology workup for various indications. Twenty of the 32 patients also had conventional coronary angiography 1–3 weeks before or after CTCA. Criteria for exclusion included irregular heart rate, allergy to iodine contrast media, impaired renal function, and lack of cooperation. All the patients signed an informed consent after receiving a full explanation of the procedure.

The study population was further subdivided, according to the indication for CTCA, into the following four subgroups:

MDCT = multi-detector computed tomography
CCA = conventional coronary angiography
CTCA = CT coronary angiogram

- Group A – symptomatic patients with known or suspected ischemic heart disease who underwent both CCA and CTCA within 3 weeks as part of their evaluation (n=12)
- Group B – cardiac patients post-diagnostic CCA who remained partially diagnosed despite CCA (n=6, four with suspected ostial coronary stenoses and two with ectopic right coronary artery and suspected squeezing of the RCA by the great vessels)
- Group C – patients after open heart surgery with various suspected unusual anatomic derangements who were referred to CTCA following a non-diagnostic CCA, transthoracic and/or trans-esophageal echocardiogram (n=4, left ventricular pseudoaneurysm, recurrent type A aortic dissection with possible coronary graft involvement, aortic valve replacement with aortic graft, and suspected left anterior descending artery obstruction and a coronary fistula [RCA to left atrium] post-mitral valve replacement)
- Group D – symptomatic post-coronary artery bypass graft patients who were referred for CTCA before considering repeat CCA (n=8).

CTCA was performed using a four-slice multi-detector spiral CT scanner (GE Light-Speed Plus, Milwaukee, USA) with dedicated cardiac reconstruction software. Oral beta blockers (atenolol 25 mg) were given to all patients who were not already taking beta blockers, 3 hours prior to the examination. Intravenous beta blockers (propranolol 1–4 mg) were added immediately before acquisition in cases with a heart rate >70 beats per minute. A flow of 4 L/min O_2 was administered via a facial mask throughout the examination. The scan volume was determined from the carina to 1 cm below the diaphragmatic surface of the heart. In patients after CABG the scan was started at the dome of the aortic arch. Time to peak was calculated using Smart Prep® software (USA). Coronary enhancement was achieved with 100–140 ml intravenous non-ionic contrast agent (Ultravist 370, Schering AG, Germany) injected at a rate of 4 ml/sec to the right antecubital vein.

The scan was performed in a cranio-caudal direction, 140 KV/240 mA at 0.5 sec gantry rotation. Slices were acquired using 1 mm collimation and 50% overlap; 15 cm of heart volume were scanned at a pitch of 1–1.5 according to the heart rate. The scan time was approximately 30 seconds, allowing single breath-hold acquisition in all patients. Images were reconstructed in different phases of the cardiac cycle (mostly late diastole) using a retrospective ECG-gated reconstruction algorithm.

Post-processing and data evaluation

All sets of images were first analyzed in their original two-dimensional format. These original images provided a better delineation of the vessel wall as well as detailed information of the cardiac anatomy, the size of cardiac chambers, and myocardial thickness.

RCA = right coronary artery
CABG = coronary artery bypass graft

Table 1. CTCA results for coronary stenosis exceeding 50% in 157 coronary segments in 12 patients as compared with CCA

Vessel segments	Assessable total	True positive	False negative	False positive
RCA, proximal	12/12	0	0	0
RCA, middle	10/12	3	0	1
RCA, distal	9/12	1	0	0
PDA	6/12	2	1	0
LM	11/11	2	0	0
LAD, proximal	12/12	2	1	1
LAD, middle	12/12	2	0	2
LAD, distal	10/12	0	0	0
1st diagonal	9/12	0	0	0
2nd diagonal	10/11	0	0	0
LCX, proximal	10/12	1	1	0
LCX, marginal	10/10	1	1	0
LCX, distal	5/11	0	1	0
Distal marginal	3/6	0	0	0
PDA	2/2	0	0	0
Total	131/157	14	5	4

PDA = patent ductus arteriosus, LM = left main, LCX = left circumflex.

Using dedicated software for cardiac analysis (GE Card IQ Analysis®, USA), multi-planar reconstructions, maximum intensity projections and volume-rendered reconstructions of the heart and each individual coronary vessel were performed and analyzed. A 3-point scale was used to assess the degree of stenosis – normal, low grade (less than 50%), and high grade (above 50%).

Coronary angiograms (CCA) were performed using the conventional Judkins technique in multiple projections (five for the left and three for the right coronary system), using 80–120 ml Ultravist 370 (Schering AG, Berlin, Germany). Angiograms were reviewed by two experienced cardiologists who were blinded to the CTCA results. By-segment coronary analysis was performed using the modified American Heart Association 15 segments classification [15]. All segments of the four main coronary branches – i.e., left main, left anterior descending, left circumflex and right coronary artery and their side branches greater than 2 mm in diameter – were identified and screened [Table 1]. Although 20 patients had both CTCA and CCA, 8 patients underwent CCA with interventional procedure (balloon dilatation or stent insertion) prior to the CTCA.

A comparison between CCA and CTCA in terms of detailed coronary anatomy (157 coronary segments) was carried out only among 12 patients from groups A and B. CTCA was analyzed first by two independent observers (a radiologist and a cardiologist) who were blinded to the CCA results. CCA results were analyzed by one cardiologist who was blinded to the CTCA results. In case of disagreement, a final decision was reached by consensus.

Following a computation of the assessability rate among all segments analyzed by both methods, the sensitivity, specificity, and positive and negative predictive values were calculated, first for all assessable vessel segments and then for those >2 mm in diameter.

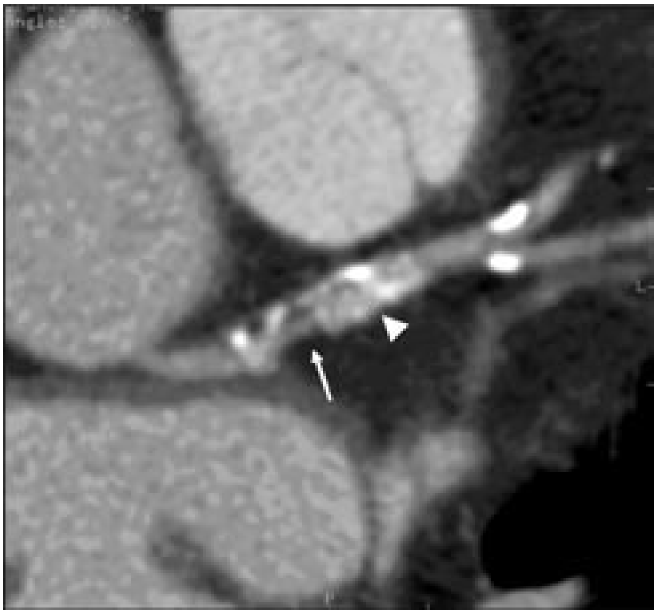

Figure 1. Transverse base image of the heart demonstrating atherosclerotic plaque with a high grade LAD stenosis (arrow), proximal to a LAD stent (arrowhead).

Figure 2. Oblique transverse maximum intensity projection of the heart demonstrating an ectopic right coronary artery originating in the left sinus of valsalva. External pressure on the proximal RCA passing between the ascending aorta and the pulmonary trunk results in an infundibular 60% RCA stenosis (arrow).

Results

The examinations were successfully performed and without complications in 30 of the 32 patients. Two patients had rapid heart rate and arrhythmia resulting in suboptimal CTCA, and were therefore excluded from the study.

As shown in Table 1, 83% of all segments could be satisfactorily assessed (131/157 segments). The reasons for non-assessability were cardiac motion in 10 segments, vessels <2 mm in diameter in 14 segments, and very heavy calcifications in 2 (a total of 26 non-assessable segments). If we limit the analysis to vessels with a diameter ≥2 mm, the overall assessability was 92% (131/143 segments). The overall sensitivity was 74% (85% for main vessels). The specificity was 96%, with a positive predictive value of 71% and negative predictive value of 97%. Figure 1 displays a high grade stenosis in the LAD as demonstrated with CTCA.

Group B included two patients with chest pain and known ectopic right coronary artery, diagnosed with CCA, who were referred to CTCA to confirm a possible malignancy. The first patient revealed an external compression of the ectopic RCA passing between the ascending aorta and the pulmonary trunk [Figure 2]. This patient was operated for de-roofing of the anomalous right coronary artery and was referred again for re-evaluation with CTCA, which showed low grade stenosis of the ostium. The second patient with anomalous RCA origin showed no evidence of external compression, but revealed a low grade ostial stenosis that was not visible on the conventional coronary angiogram. Four patients with angina underwent CTCA for suspected ostial-coronary artery stenosis that could not be confirmed with CCA. As shown in Table 2, among the four patients referred, CTCA confirmed a high grade RCA ostial stenosis in only one patient who was subsequently operated, while the other three patients were treated medically and are doing well (asymptomatic for over 12 months).

Table 2. Four cases where severe ostial stenosis was suspected in CCA*

CCA	CTCA	Treatment
LAD, 80%	Normal	Medical
RCA, 95%	Ostial RCA, 90%	CABG
LM, 70%	LM, 50%	Medical
LM, 70%	LM, 50%	Medical

* Treatment recommendation was based on CTCA results

In group C, CTCA proved very helpful in demonstrating the exact anatomy. One patient, 3 weeks after CABG and pericardial patch for pseudoaneurysm of the left ventricle, suffered from chest pain and severe anemia. Echocardiogram demonstrated a right paracardiac hypoechoic collection that was interpreted as post-surgical pericardial hematoma. CTCA clearly showed a leak from the left ventricle via a transmural basal fistula into a large paracardial pseudo-aneurysm. Emergency surgery was performed, which confirmed the CTCA findings. In another patient after CABG and recurrent type A aortic dissection, CTCA clearly demonstrated the internal flap distal to the coronary graft in

LAD = left anterior descending artery

the ascending aorta. With regard to the remaining two patients in this group, one had undergone aortic valve replacement and composite aortic graft with suspected LAD obstruction, and the second had suspected RCA to the left atrium fistula after mitral valve replacement. The diagnosis was confirmed with CTCA in both cases.

In group D, among the 24 grafts evaluated, only 17 (70%) were fully assessable (including both proximal and distal anastomoses, as well as the whole length of the graft). In the remaining seven grafts the reasons for non-assessability were motion artifacts (three grafts), X-ray beam hardening from a metallic cluster or clip (two grafts), or insufficient contrast filling (two grafts).

Discussion

The appearance of non-specific chest pain a short time after a coronary stent implantation or a CABG operation, together with the absence of definitive results of a stress test or thallium scan in a patient with precordial pain, usually generate a conflict regarding repeated coronary angiography. There is an unavoidable need for reevaluation of the coronary tree on the one hand, but a very low expectation for pathologic findings on the other.

The usefulness of multi-slice computed tomography for detecting occlusive coronary artery disease has already been widely documented in both the radiologic and cardiologic literature [4–20]. This technique reduces the need for invasive procedures, thereby reducing the budgetary stress on hospitals and outpatient clinics.

Our study included a relatively small and non-homogeneous group of patients. The principal aim was to evaluate the relative advantage of CTCA as a primary diagnostic procedure in specific clinical set-ups or when faced with controversial diagnostic issues that arise with different diagnostic modalities. All 32 patients underwent CTCA using the same acquisition protocol and post-processing techniques, with no special consideration for the clinical indication for the procedure.

Several clinical trials comparing CTCA with a four-slice scanner to CCA have shown 75–85% sensitivity and 76–93% specificity for significant (>50%) coronary stenosis [4–8,10,11,13]. Our results were similar to those of already published studies with larger groups that used a four-detector row scanner and the same or similar acquisition protocol. Furthermore, the advent of faster 16, 40 and 64-slice MDCT scanners increases the number of assessable coronary arteries and improves the overall accuracy of CTCA. In published studies in which 16-slice scanners were used, the sensitivity and specificity rates ranged from 92 to 95% and 92 to 95% respectively [9,12,14]. Previous studies show a high rate of agreement regarding the high negative predictive value of a negative CTCA, reaching 97% with 16-slice scanners [5–7,9,10,12,18]. This fact suggests that CTCA can be used for excluding coronary artery disease in patients with equivocal clinical presentation and test results. The more detailed depiction of the coronary artery wall and arteriosclerotic plaques will undoubtedly become the subject of thorough research in the coming years.

Most studies agree that diagnostic image quality is inversely related to the patient's heart rate [10,21–23] and recommend oral administration of beta blockers to slow down the heart rate in patients undergoing CTCA to less than 60 beats/min using a four-slice MDCT and less than 70 beats/min when using a 16-slice scanner. It is expected though, that future scanners with additionally increased speed and improved temporal resolution will diminish the remaining motion artifacts and correspondingly increase sensitivity and specificity.

For all patients in groups B and C in our study, CTCA provided information that was either missed or misinterpreted in other modalities, but nevertheless was critical for the correct management of the disease. In these groups the three-dimensional capabilities of post-processed CTCA was of great value for understanding complex anatomic abnormalities. Some of these patients were very ill and/or unstable at the time of examination, which made the magnetic resonance imaging alterative less suitable.

We considered the patients in group B (ostial coronary stenosis) of the utmost importance to the study, because reliable evaluation of the ostium can be very problematic with CCA as the catheter is situated at the orifice of the artery. False-positive high grade ostial stenosis was suggested, attributable to arterial spasms secondary to the catheter positioned in the proximal vessel. CTCA is very suitable for the evaluation of the ostium and proximal coronary vessels; however, since these patients are sent for evaluation of a specific site (e.g., LAD ostium), the examination, although already very short, can even be reduced to the few centimeters of the proximal ascending aorta, thereby reducing both exposure time and the amount of contrast material to be injected. We contend that CTCA can provide vital information to resolve the issue of structural versus functional (spastic) ostial coronary artery stenosis.

In group D, the 70% full-length graft visualization, although better than the 62% reported in a previous study in a much larger population [16], represents a major limitation. The main reasons for impaired image quality were motion artifacts, poor vessel opacification (mostly in thin grafts), and X-ray hardening artifacts related to metal clips. A recent study with a four-slice CT scanner found 93%–100% sensitivity and 97.8–98.7% specificity for the diagnosis of complete occlusion of the arterial and venous coronary grafts [24]. Improved sensitivity (96%) and specificity (95%) for graft stenosis were found using the newer generation 16-slice scanner [25], reinforcing the use of CTCA in this group of patients.

CTCA may provide extremely valuable information before using CCA. Familiarity with the exact anatomy of the bypass grafts makes CCA a shorter and more focused procedure with decreased exposure time and contrast medium dose. CTCA has several advantages over CCA. It is a simple, rapid and non-invasive examination performed with an intravenous contrast injection without the need for catheter insertion with its subsequent sequelae. The examination enables volumetric acquisition that allows flexibility and variability in image reconstruction, including three-dimensional and virtual images of the heart components. CCA has the capability of demonstrating only the vessel lumen, while CTCA is able to demonstrate the vessel lumen, wall and the perivascular tissue. This is extremely important for the evaluation of calcified plaques, especially flat non-calcified plaques that can be missed with CCA. CT examination of the heart allows different cardiologic evaluation with the same acquisition, providing information that is usually obtained by multiple cardiologic methods such as CCA, echocardiography, thallium scan, etc. CTCA can be applied for the assessment of coronary artery anomalies as well as for follow-up after surgical and percutaneous revascularization procedures.

The new generation CT machines with improved accuracy for stenosis detection will probably be used in the near future as a primary screening tool in asymptomatic patients with high risk for coronary disease and in patients with atypical chest pain and equivocal stress test and/or thallium scan.

Study limitations

The technology of CTCA has evolved further since this study was conducted but the population investigated is limited. In contrast to groups A and D that can be compared with previous studies, the results in groups B and C need to be confirmed in further studies with larger populations.

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I have yet to hear a man ask for advice on how to combine marriage and a career.

Gloria Steinem (1934-), America's most influential, eloquent and revered feminist