Detection of Coronary Artery Stenoses with Thin Slice Multi Detector Row Spiral Computed Tomography Angiography

SHERIF MOHAMED MAHER, MBCH*, IHAB ISMAIL ALY, M.D.*, NASHWA ABED MOHAMED, M.D.** and MOHAMED ABD EL-FATTAH HASSAAN, M.D.*

The Departments of Radiodiagnosis* and Critical Care**, Faculty of Medicine, Cairo University

Abstract

Background: Multislice CT coronary angiography is a recent technique used to diagnose coronary artery diseases with better spatial and temporal resolution.

Objectives: To detect stenosis in the coronary arteries using thin slice multidetector row CT coronary angiography.

Methods: A total number of 15 patients scheduled for elective conventional coronary angiography for known or suspected coronary artery disease were enrolled for multislice CT angiography of the coronary arteries. 5 patients with previous CABG operation and other 3 patients with percutaneous trans-luminal coronary angioplasty (PTCA) and stenting were included.

Results: CT coronary angiography detected significant and non-significant stenoses in the native arteries and evaluated the patency of the grafts, conduits and stents in post interventional cases.

Conclusion: The improved spatial and temporal resolution of the CT coronary angiography makes it capable of detecting stenosis in the coronary arteries, diagnosing coronary artery anomalies and proper evaluation of the grafts and stents.

Key Words: Coronary artery disease (CAD) – Multislice computed tomography (MSCT) – Computed tomography angiography (CTA).

Introduction

CORONARY artery disease (CAD) remains a leading cause of death all over the world. The standard reference for diagnosis of CAD is still the conventional coronary angiography. The greatest advantage of conventional angiography is the perfect spatial resolution and the option of direct performance of interventions such as balloon dilation or coronary stent placement. However, only one-third of all conventional coronary angiographic examinations are performed in conjunction with an interventional procedure, while the rest are performed only for diagnostic purposes (American Heart Association 2002).

Recent insights into the patho-physiology of atherosclerotic CAD suggest that coronary arterial wall structure has a crucial role in these disorders. Since coronary angiography depicts only the intraluminal morphology but not the wall, much research effort has been focused on other imaging modalities. MSCT, unlike conventional angiography, enables assessment of the vessel wall abnormalities [1].

Until recently, CT applications for the assessment of CAD per segment were almost exclusively directed at the detection and quantification of coronary arterial calcium. In recent years, considerable interest has accordingly been directed at the beneficial use of high-spatial-resolution contrast enhanced CT angiography for noninvasive interrogation of the coronary arterial tree. To date, the central rationale of this application has been the noninvasive detection and grading of coronary artery stenosis and follow-up after coronary bypass surgery, with the ultimate goal of replacing diagnostic invasive conventional coronary angiography [2].

Challenges in evaluating the coronary arteries at CT are the small size of the vessels, their tortuous courses and fast continuous movement. Possible solutions are imaging on scanners with an increasing number of detector rows, faster rotation speeds and reconstructing multiple sets of images obtained in different phases of the cardiac cycle (ECG gating) from a volume acquisition. The challenges of CT angiography of the coronary arteries have been partially met and will likely be addressed with the continued evolution of technology [3].

However, CT angiography, among the non-invasive methods for assessment of the coronary
Detection of Coronary Artery Stenoses

arteries, currently appears to be the best owing to its combination of unprecedented acquisition speed, high spatial resolution, and robustness of use [4].

Since the clinical outcome of the patients is closely related to the patency rate of their bypass grafts, it would be important for the patients to have the patency rate of their grafts assessed on time to detect any graft occlusion before the majority of the grafts get occluded. Recently, multislice computed tomography offers an attractive tool for this purpose. Bypass grafts are ideal vessels for evaluation by MSCT because of their greater diameter and their relative spatial fixation [4].

The aim of this study is to evaluate the accuracy of the multislice CT coronary angiography, as a non-invasive imaging tool for morphological assessment of the coronary arterial tree to detect stenosis and also to detect calcification, location and severity of obstruction of the coronary plaques.

Patients and Methods

Study population:

A total number of 15 patients (12 males and 3 females) with a mean age 56 years old (ranging between 43 and 65 years old) were scheduled for elective conventional coronary angiography for known or suspected coronary artery disease were enrolled for multislice CT angiography of the coronary arteries. These patients presented with ischemic chest pain (defined as a retro-sternal or precordial diffuse burning, heaviness, or squeezing sensation that may radiate to the left arm, neck or lower jaw and is precipitated by effort and relieved by rest or nitrates) or suspected progression of known coronary artery disease. Some of them had history of previous percutaneous trans-luminal coronary angioplasty (PTCA) and stenting (n=3) or coronary artery bypass graft (CABG) surgery (n=5). In the group with previous history of CABG surgery (n=5); a total number of 13 grafts were to be evaluated, with an average of three grafts per patient. The major inclusion criterion was scheduling for conventional coronary angiography. Patients enrolled in this study had to fulfill the following criteria: sinus heart rhythm, hear rate below 70beats/min, able to hold breathe for accepted time (30 seconds) and normal serum creatinine. Exclusion criteria were; irregular heart beats (arrhythmias), contra-indications to iodinated contrast material including known allergy and renal insufficiency (serum creatinine more than 1.4mg/dl), contra-indications to radiation exposure i.e. pregnancy, respiratory impairment (inability to withhold breathing), and unstable clinical status or marked heart failure.

Patient preparation:

All patients are instructed to fast 6 hours prior to the examination and medications are not to be discontinued.

Before the examination; the heart rate was evaluated. Patients with pre-examination heart rates above 65-70beats per minute were given cardio-selective beta-blocker; 100mg of Metoprolol or atenolol orally 1 hour before the study to obtain a stable low heart rate, provided that contra-indications to B-blockers are excluded. If the heart rate was still above 75beats per minutes, the examination was postponed to another setting. Nitroglycerine was not administrated prior to the study because, in spite of its coronary-dilator effect that enhances visualization; the drug has the potentiality to increase the heart rate and also falsely increases the estimated diameter reduction of the stenotic lesions.

All steps of the study were explained in details for each patient. To evaluate patients ability of breath-withholding for the time of examination; they were required to perform a deep inspiration and to continue to hold their breath without pushing (i.e., Valsalva maneuver). During this trial, the patient was observed for compliance and the electrocardiogram for significant changes.

Contrast material:

A bolus of 120ml of non-ionic contrast (Ultravist 370 Schering, Berlin, Germany), was injected through 18-gauge canula into an upper limb vein (right antecubital vein is preferred when available) with a flow rate of 4-5mL/sec using a programmed power injector pump. Another bolus of 30ml saline is injected following the contrast as a chaser bolus used to wash the contrast from the right side of the heart during visualization of the RCA.

Scan protocol:

CT scans were done at Cairo radiology center using a sixteen channel multi-detector row CT scanner (CT sensation; siemens medical systems). Scanning parameters were: 16 x 0.75mm collimation, pitch 2 according to the estimated heart rate (decreased at higher HR to increase the image segments overlap yet on the expense of increased total scanning time and breath hold), tube rotation time of 370msec, tube voltage of 120KV (increased to 140KV in obese patients and in cases with previous CABG, owing to presence of dense metallic issues near the grafts) and current of 350mA. The field of view is 250mm with an image matrix of
256 x 256 pixels. Scanning direction; cranio-caudal. The patient is then positioned supine on the CT table. ECG leads are fixed at the four corners of the pericardium. All reconstructions are performed using the retrospective ECG gating. For this technique; an ECG must be recorded simultaneously through out the duration of the scanning. Each stage of acquisition was preceded by the same gentle hyperventilation protocol, which took 20 seconds.

First; a localization scan (scanogram) is performed that yields an antero-posterior view of the chest. It is used to position the imaging volume of the coronary arteries that extends from the level of the carina down to about 1cm below diaphragm. The center of the field of view is 2cm to the left of the dorsal spine on the AP scout. In cases with previous CABG operation; the scanning range was extended to include the entire course of the arterial and venous grafts.

An initial step of non-contrast CT examination of the heart was performed for all patients in order to detect and quantify coronary calcifications through the volume extended from below the carina to the apex of the heart. Acquisition parameters were ECG gated at 60 % of the RR interval, 370ms gantry rotation, 16 x 0.75mm collimation, 350mA, and 120kV. To minimize the total effective patient radiation dose, this stage of the scanning was conducted with a relatively low tube current. Cases with high coronary calcium score (above 1000) were shifted directly to conventional coronary angiography. In a third step, semi-automated determination of the starting time using the “Bolustracing technique” was utilized in all patients. It entails injection of the whole volume of the utilized contrast material as a one bolus at the pre-determined rate. After a delay of about 10 seconds from the start of injection (time estimated for the contrast to reach the great vessels of the chest, being variable according to the site of the canula, rate of injection, body built and heart rate); series of axial images at the level of the origin of the left main coronary artery is acquired with an interval of 1 second between subsequent images. The density within the ascending aorta is monitored in each axial image on a real time base while the region of interest (ROI) carefully avoiding the athermanous calcifications. Time-attenuation curves were generated. When the density within the ascending aorta exceeds 100HU (i.e. the contrast started to arrive), the scanning is triggered with a delay of further 3 seconds (time needed for the table movement to the cranial start position while the patient is instructed to hold breathing). This time delay also allows for increase in the contrast concentration at the ascending aorta and coronary arteries.

Finally; the volume data set for coronary artery visualization is acquired in a spiral mode with simultaneous acquisition of 16 parallel slices at certain scan parameters. During the helical scan; the ECG signal was recorded digitally. Patients were automatically instructed to maintain an inspiratory breath hold while the CT data and the ECG trace were acquired. The volume between the level of the carina and the base of the heart (120mm) was covered in 18+2 seconds in the 16 detector-row CT scanner.

In cases with known previous CABG surgery; the mean scanning time was increased to 30+2 seconds in the 16 detector-row CT scanner. Mean heart rate during time of examinations was 65beats per minutes. Bolus timing procedures and main acquisitions were performed in all patients with no clinically important adverse reactions to contrast material. Despite that the CT scan is completed within a couple of minutes; the total examination time (including the patient preparation and instruction) was around 20 minutes.

Scan parameters:

All CT angiographic examinations were done on CT sensation 16-detector row CT scanners (n= 15; 10 cases for evaluation of the native coronary arteries and 5cases for evaluation of the bypass grafts as well) (Siemens Medical Systems, Germany).

Scanning parameters were: 16 x 0.75mm collimation, pitch 2 according to the estimated heart rate (decreased at higher HR to increase the image segments overlap yet on the expense of increased total scanning time and breath hold), tube rotation time of 370msec, tube voltage of 120KV (increased to 140KV in obese patients and in cases with previous CABG, owing to presence of dense metallic issues near the grafts) and current of 350mA. The field of view is 250mm with an image matrix of 256 x 256 pixels. Scanning direction; cranio-caudal.

Image reconstruction:

Cardiac phase pre-selection in this study was influenced by the results obtained by Achenbach, et al., 2000 [8] with regard to coronary artery motion on transverse electron-beam CT images and also those obtained by Kopp A.F., et al. 2001 [6]. They found that LMT could be clearly visualized at almost all time points in the cardiac cycle. For most patients, LAD was best visualized at 60%-70% of the cardiac cycle. The time point for best
Detection of Coronary Artery Stenoses

Image quality of the RCA was early in diastole at 40% of the cardiac cycle. The LCX showed optimal image quality at 50% of the cardiac cycle with considerable inter-patient variation. And so, for each patient; 6 data sets were created during different time instants of the cardiac cycle (30%, 40%, 50%, 60%, 70% and 80% of the R wave to R wave interval). Time needed to reconstruct an axial image is about 2 seconds; and so it takes about 30min to create this large number of images. For each individual coronary artery; the data set containing the fewest motion artifacts (on the bases of cross sectional images) was used for further creation of the reconstructed images and evaluation of the coronary artery. The average time of the study was 20 minutes. Another 60 minutes were spent for result evaluation at the workstation.

Data evaluation:

The reconstructed axial images at different points of the cardiac cycles are sent to an off-line workstation. Dedicated cardiac reconstruction software was used to evaluate the coronary arteries. Total calcium scores of all patients were calculated with the dedicated software and expressed as Agatston scores. Using the sequential axial images; any tissue above the 130HU occupying a minimum of 0.5 mm$^2$ could be identified along the anatomical course of a coronary artery is considered as coronary calcification, and hence, highlighted and analyzed using the software. The Agatston score is a commonly used scoring method that calculates the total amount of calcium on the basis of the number, areas, and peak Hounsfield units of the detected calcified lesions. Visibility of the coronary artery segment was considered “good” when there is sharp delineation from the surrounding structures, nearly artifact-free course of the segment, with less blurring even in its peripheral sections and sufficient contrast detected between the vessel lumen and wall. Visualization was considered “adequate” in presence of image-degrading artifact that didn’t interfere with evaluation with moderate confidence and “poor” in the presence of image-degrading artifacts when the evaluation is possible yet only with low confidence. The examined segment was considered “non-assessable” when the image-degrading artifacts were severe enough to prevent differentiation between the significant stenosis and occlusion on one hand and the normal segment or mildly atherosclerotic lesions on the other hand. These segments were excluded from the study. When there is doubt regarding the image quality, it was determined by measuring the mean CT density within the artery lumen and the mean CT density in the connective tissue immediately next to the coronary artery. These values are referred to the standard density at the ascending aorta. Better image quality was achieved with larger difference between the arterial lumen and the surrounding tissues and with higher contrast density within the ascending aorta.

Identification of coronary artery segments was based on the model suggested by the American Heart Association (AHA) (Fig. 1), where the RCA shows proximal (1), middle (2) and distal (3) segments and the PDA branch (4). The left coronary system is formed by the left main trunk; LMT (5) that bifurcates to LAD and left circumflex. The LAD has proximal (6), middle (7) and distal (8) segments. It gives off at least two sizable diagonal branches (9) and (10). The left circumflex artery has proximal segment (11) before it gives off the first obtuse marginal artery (12). The distal segment (13) turns on the inferior surface of the heart. LCX may give additional obtuse marginal branches (14) and (15) that are not included in statistics of this study owing to their usual small size.

Fig. (1): Segmental anatomy of right coronary artery (RCA) (lateral view), and left coronary artery (right anterior oblique view) with left main trunk (LMT), left anterior descending (LAD), and left circumflex (LCX) according to American Heart Association (AHA) [6].
The coronary artery segments are further classified into proximal [RCA 1, LMT 5, LAD 6], middle [RCA 2, LAD 7, LCX 11], distal [RCA 3, LAD 8, LCX 13] and branches [including the diagonals of LAD (9 and 10), obtuse marginal of the left circumflex (12) and posterior descending artery (4)].

**Results**

Multislice CT coronary angiography was performed to all patients without complications. In our study, 15 patients were included and here are the following results. The total number of examined segments was 195 considering 13 segments in each of the examined 15 coronary systems according to the model suggested by the American Heart Association (AHA). However, in 4 patients; the second diagonal artery was not identified at CT. Hence; the total number of examined segments is reduced to 191 (Table 1).

Each segment was evaluated at the axial images at proper R-R interval, and then different post-processing techniques, including multi-planner and curved reformations, maximal intensity projection and volume rendering, some or all of them were employed in an integrated manner to reach the diagnosis.

The coronary segments were classified as evaluable or non-evaluable depending on the image quality (being mainly assessed at the sequential axial images). The non-evaluable arteries are discarded from the statistical analysis. The evaluable arteries are categorized as being either (A) Normal (smooth parallel or tapering arterial walls), (B) Showing either coronary artery wall irregularities or non-significant stenotic lesion(s) (with less than 50% diameter reduction) (C) Showing significant stenotic lesion(s) (defined as equal to or more than 50% diameter reduction; according to AHA classification), or (D) Occluded.

**The reconstruction window:**

For each patient; 6 data sets were created during different time instants of the cardiac cycle (30%, 40%, 50%, 60%, 70% and 80% of the R wave to R wave interval). For each individual coronary artery; the data set containing the fewest motion artifacts (on the bases of cross sectional images) was used for further processing of the reconstructed images and evaluation of the coronary artery.

The distribution of the image reconstruction window with least motion artifacts relative to the cardiac cycle is given in (Table 1).

The left main and LAD arteries were best visualized in mid-diastole at 60-70% for most patients. The time point for best image quality of the right coronary artery was different being at 40%. The left circumflex artery showed optimal image quality most frequently at 50-60%.

The total number of examined segments was 195 considering 13 segments in each of the examined 15 coronary systems according to the model suggested by the American Heart Association (AHA). However, in 4 patients; the second diagonal artery was not identified at CT. Hence; the total number of examined segments is reduced to 191.

To start with, each segment was evaluated at the axial images at proper R-R interval, and then different post-processing techniques, including multi-planner and curved reformations, maximal intensity projection and volume rendering, some or all of them were employed in an integrated manner to reach the diagnosis.

**Diseased vessels per case:**

Among the 15 patients; the CT coronary angiography showed one vessel disease (i.e. significant stenotic lesion or occlusion) in 3, and three vessel disease in 12 patients.

**Distribution of the diseased vessels:**

CT coronary angiography revealed a total number of 50 stenotic segments, 39 of them show significant stenosis while the other 11 segments show non significant stenosis and other 5 segments show complete occlusion. The total number of diseased segments is 55 segments. Their distribution is tabulated in (Table 2).

**Evaluation of coronary stents:**

Seven coronary stents in 3 patients were evaluated for patency, in-stent re-stenosis and occlusion. The stents were distributed as 2 in the RCA, 3 in the LAD and 2 in the Cx arteries. According to the CT angiographic findings; 5 stents were patent while the other two showed in-stent re-stenosis depending on the indirect sign of faint contrast opacification distal to the stent rather than actual detection of lumen narrowing.

**Group of patients with previous CABG surgery:**

The total number of examined patients with previous CABG surgery is 5 having a total number of 12 conduits with an average of 2 conduits per patient. In 4 of these conduits; the left internal mammary artery (LIMA) was used to enforce the blood supply in the left coronary system being inserted at the distal LAD segment. One patient has right internal mammary artery (RIMA) used...
to enforce the blood supply in the left coronary system being inserted at the circumflex artery. 7 arterial and venous grafts were also studied; 2 of them were inserted distally at the LAD, 2 at the RCA, one at the PDA, one to the circumflex artery and finally, another one to the OM.

**Evaluation of the LIMA and RIMA:**

There were 4 cases of LIMA and one RIMA case. The LIMA anastomosis was to the distal LAD artery while the RIMA anastomosis was to the circumflex artery. The evaluation consists of evaluation of the body and the distal anastomotic end with the RCA (Table 3). The LIMA conduits were patent as well as their distal anastomotic sites (Table 3).

**Evaluation of the bypass (arterial and venous) grafts:**

The 7 bypass grafts included in the study were evaluated regarding their proximal anastomotic site at the ascending aorta, body and the distal anastomotic sites. 6 of the 7 grafts showed patent body as well as proximal and distal anastomotic ends while the other case shows some degree of stenosis in its proximal anastomotic end with the ascending aorta and patent body and distal anastomotic end with the RCA (Table 4).

### Table (1): Showing distribution of the image reconstruction window with least motion artifacts relative to the cardiac cycle.

<table>
<thead>
<tr>
<th>Cardiac cycle</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>40%</td>
</tr>
<tr>
<td>LAD</td>
<td>–</td>
</tr>
<tr>
<td>Cx</td>
<td>–</td>
</tr>
<tr>
<td>RCA</td>
<td>–</td>
</tr>
</tbody>
</table>

### Table (2): Showing the distribution of the diseased coronary artery segments.

<table>
<thead>
<tr>
<th>Segments</th>
<th>Sig. stenosis</th>
<th>Nonsig. stenosis</th>
<th>Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Sig. stenosis</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Nonsig. stenosis</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Occlusion</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

P = Patent.  
SS = Nonsignificant stenosis.  
A = Atherosclerotic.  
ST = Stent.  
NA = Nonassessable.

### Table (3): Showing the CT angiographic findings for each coronary segment for all the examined 15 cases where.

<table>
<thead>
<tr>
<th>seg. case</th>
<th>RCA</th>
<th>LM and LAD</th>
<th>Cx</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>A</td>
<td>P</td>
</tr>
<tr>
<td>3</td>
<td>P</td>
<td>P</td>
<td>SS</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>A</td>
<td>SS</td>
</tr>
<tr>
<td>5</td>
<td>O</td>
<td>ST</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>7</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>8</td>
<td>P</td>
<td>ST</td>
<td>NSS</td>
</tr>
<tr>
<td>9</td>
<td>SS</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>10</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>11</td>
<td>NSS</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>12</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>13</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>14</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>15</td>
<td>P</td>
<td>NSS</td>
<td>NSS</td>
</tr>
</tbody>
</table>

P = Patent.  
SS = Nonsignificant stenosis.  
A = Atherosclerotic.  
ST = Stent.  
NA = Nonassessable.

### Table (4): Showing the CT angiographic findings for the five LIMA and RIMA conduits used to enhance the coronary circulation.

<table>
<thead>
<tr>
<th>Case</th>
<th>Body</th>
<th>Distal anastomosis</th>
<th>Case</th>
<th>To</th>
<th>Proximal end</th>
<th>Body</th>
<th>Distal end</th>
</tr>
</thead>
</table>
Case (1): Male patient 51 years old, not known to be hypertensive or diabetic, presented for the last two months by intermittent attacks of mild chest pain and so he came to perform CT coronary angiography. There is no history of previous cardiac operations. The total estimated calcium score was 23.2. The LAD artery shows two atheromatous plaques, a soft and another mixed one in its proximal segment. They cause about 30 and 40% lumen reduction respectively.
Case (2): Male patient 52 years old, known to be diabetic and hypertensive, presented for the last one month by intermittent attacks of staggering chest pain and so he came to perform CT coronary angiography. There is no history of previous cardiac operations. The total calcium score for the coronary arteries was 272.7 represented by calcific plaques seen at the RCA, LAD and Cx arteries. The RCA is a dominant artery that gives PDA branch. It shows a soft plaque that arises shortly after its origin and it causes significant lumen reduction more than 60%. Two other mixed plaques are seen in the middle segment of the artery that causes significant about 80% lumen reduction. The distal segment of the artery as well as the PDA is seen diffusely attenuated.

The Cx artery is diffusely attenuated and its distal half shows multiple consecutive atheromatous calcific plaques markedly encroaching on the lumen and causing significant lumen reduction.

The distal portion of the LM coronary artery shows a mixed plaque that is seen extending in the proximal portion of the LAD and causes less than 50% lumen reduction.
Case (3): Male pt 61yrs old is known to have IHD & he has a history of graft operation to the coronary arteries 2yrs ago. Diabetic & on treatment. He is performing CT coronary angiography as a check up. A large atheromatous mixed soft & calcific plaque is seen at the distal part of the LM coronary artery & it is seen extending to the proximal portion of the LAD subtotally obliterating it. A venous graft is seen connected to the ascending aorta while its other end is seen anastomosed to the LAD artery, which shows adequate opacification by contrast material distal to the graft.

The Cx artery shows a mixed atheromatous plaque at its ostium markedly encroaching upon the vessel lumen

The RCA is a dominant artery that shows subtle atherosclerotic changes of no significance.
Case (4): A male patient 59 years old is known to be diabetic but not hypertensive. He is complaining of intermittent attacks of mild anginal pain in the form of discomfort. His doctor advised him to perform a conventional cardiac catheterization, but he refused and appreciated to have a CT Coronary angiography performed to him. He has no history of cardiac operations. The left and right coronary arteries are seen arising from the ascending aorta by a short common trunk. The LM coronary artery then bifurcates into LAD and Cx arteries.

The RCA shows small soft atheromatous plaques in its proximal portion causing wall irregularities and insignificant lumen reduction.

The LAD and Cx arteries are patent and of normal caliber showing tiny calcific foci in their walls causing no significant lumen reduction. The Cx artery is a dominant artery giving OM and PDA branches.
Case (5): Male pt 55 yrs old is known to have an ischemic heart disease. He had an operation of stent application done for him 5 months ago, & recently he has a classic anginal chest pain that is only relieved on nitrates. He is diabetic & under controlled treatment. The RCA is a dominant artery. A hypodense thrombus is seen at the mouth of the RCA causing almost total occlusion of the artery. This lesion is followed by multiple consecutive metallic stents. Distal to these stents, the artery and its PDA branch are diffusely attenuated.

The Circumflex artery shows a mixed osteal lesion that causes significant stenosis. Distal to this stenosis, there is a metallic stent in the OM branch which failed to opacify by contrast distal to the stent.

The LM coronary artery is patent and it bifurcates into LAD and Cx arteries. The LAD shows a proximal stent within with distal patent well opacified artery with contrast.
Case (6): Male pt 57yrs old is known to be a heavy smoker, diabetic & hypertensive, came complaining of a classic anginal chest pain. He experienced the pain several times in the last month that was only relieved by sublingual nitrates. He has a conventional cardiac catheterization done for him & the RCA couldn’t be selectively injected by the doctor so, he sent him to perform a multislice CT coronary angiography. The total calcium score for the coronary arteries was 425.7 represented by multiple calcific plaques in the RCA, LAD & Cx arteries. The RCA is a dominant artery. It shows an abnormal origin where it arises from the left aortic cusp, just anterior to the LM coronary ostium, then it courses a malignant course between the root of the pulmonary artery & the ascending aorta, where it is seen markedly attenuated at this area. The middle segment of the RCA shows mixed atheromatous plaques predominately soft causing more than 60% lumen reduction.

The LM coronary artery is patent and of normal caliber. It bifurcates into LAD & Cx arteries. The LAD artery shows two mixed atheromatous plaques in its proximal segment causing >60% lumen reduction.

The Cx artery is patent and it shows atheromatous wall calcification with no significant lumen reduction.
Discussion

While selective conventional coronary angiography remain vital for planning and guiding catheter-based and surgical treatment of significantly stenotic coronary lesions or occlusions, the comprehensive and serial assessment of asymptomatic or minimally symptomatic stages of coronary artery disease (CAD) for preventive purposes will eventually need to rely on noninvasive imaging techniques. Cardiovascular imaging with tomographic modalities, including computed tomography (CT) and magnetic resonance imaging (MRI), has great potential for providing valuable information [4].

The first generations CT scanners used a sequential acquisition pattern, also known as “step-and-shoot”. These scanners produced an axial image while the table remained motionless and for each other slice the table moved to a different position. This sequence of events was repeated throughout the scan range. CT scanning was both time consuming and extremely sensitive to respiratory movements and was therefore not suitable for cardiac imaging. The total scan time was significantly reduced with the introduction of spiral CT scanners. The scan is performed while the patient is continuously moving at a pre-defined speed through the scanner. These scanners acquire volumetric data and cross sectional images can be reconstructed later for any anatomic region. This configuration significantly reduced the total scan time, but still was not fast enough for cardiac scanning.

Electron beam CT (EBCT) was originally developed as a research tool to study the cardiac physiology. These scanners use no moving parts for generation of the tomographic images. This technology allows very short scanning times of 50 to 100 milliseconds per image, and with this high temporal resolution, tomographic images of the beating heart can be obtained with minimal blurring or motion artifacts. Typical cardiac studies with EBCT include coronary calcium scoring, CT angiography of the coronary arteries, studying cardiac anatomy, wall motion abnormalities and myocardial perfusion [7].

Although a significant correlation between the amount of calcium score and the degree of atherosclerotic wall changes has been demonstrated, the diagnostic value of this technique is still controversial. And so, the mere identification of high grade coronary calcification alone does not inevitably deliver significant information concerning the localization of coronary plaques and the degree of stenosis. Further more, it has been often demonstrated that calcified plaques are at less risk of spontaneous rupture than the non-calcified plaques and thus bear no higher cardiac risk. On the contrary, it is mostly the soft plaque that ruptures spontaneously causing an acute cardiac incident.

Multislice CT is a recent development in the spiral CT. MSCT scanners are equipped with multiple and thinner detector rows, and has a faster x-ray tube rotation speed. These technical advances have an important impact on image quality [8]. The ability of MSCT coronary angiography to assist in the identification of asymptomatic, sub-occlusive CAD, above and beyond coronary calcium evaluation, is clear. Identifying disease in the asymptomatic phase, in low-and intermediate-risk patients, allows the targeting of therapies including statins and antiplatelets to secondary prevention goals, resulting in reduction of coronary ischemic events. It is also clear that MSCT angiography has the capability to assist in the detection of obstructive disease in native coronary arteries and bypass grafts [9].

Challenges in evaluating the coronary arteries at CT are their small size and tortuous courses and location adjacent to the moving heart. The vessels are typically 2-4mm in diameter and are parallel, oblique, or perpendicular to the axial plane in portions. In addition, they are adjacent to both atria and ventricles and therefore may be affected by cardiac motion in different phases of the cardiac cycle. Possible solutions are imaging on scanners with an increasing number of detector-rows, faster rotation speeds and reconstructing multiple sets of images obtained in different phases of the cardiac cycle [10].

The duration of the diastolic phase with little cardiac motion is inversely related to the heart rate, and hence, the heart rate plays an important role regarding the image quality during CT coronary angiography. Studies based on four-detector row CT found that the upper limit of the heart rate at which motion artifacts can be consistently minimized ranges between 65-75 beats per minute [11-15].

In this study; the pre-examination heart rate was evaluated, those with rates above 65 beats per minute were given cardio-selective (B-blocker orally 1 hour before the study to obtain a stable low heart rate, provided that contra-indications to B-blockers are excluded, that agree with [16]. If the heart rate was still above 75 beats per minutes, the examination was postponed to another setting. Nitroglycerine was not administrated prior to the
study, in contrast to [17,18] because, in spite of its coronary-dilator effect that enhance their visualization; the drug has the potentiality to increase the heart rate and also falsely increases the estimated diameter reduction of the stenotic lesions as it dilates the healthy segments according to [18].

Regarding the distribution of the image reconstruction window with least motion artifacts relative to the cardiac cycle; the left main and LAD arteries were best visualized in mid-diastole at 60-70% for most patients. The time point for best image quality of the right coronary artery was different being early in diastole at 40%. The left circumflex artery showed optimal image quality most frequently at 50-60%. This agrees with Kopp A.F., et al., 2002 [17] who found the same distribution. Motion artifacts were significantly more frequent in patients with heart rates of more than 70bpm than in patients with lower heart rates.

The analysis, interpretation, and documentation of coronary CT examinations are complex and not sufficiently standardized. Reviewing the axial images is an important step in interpretation of the CTA, but because of the tortuous course of coronary arteries, reviewing the acquired transverse sections alone is often not sufficient. Multi-planner image reformation at the sagittal, coronal and oblique planes can be displayed. Reformatted images following the major cardiac axes or the course of individual coronary artery (curved plane) are also possible. Coronary arteries are typically divided into smaller segments according to accepted angiographic classifications. These segments are then individually analyzed in longitudinal and cross-sectional planes.

Diagnosis of luminal stenosis and vessel wall changes relies on these two-dimensional projections. Advanced image procession permits display of the entire three-dimensional data set of coronary arteries. Volume-rendered images facilitate the assessment of spatial orientation but provide only limited information about the arterial lumen and the vessel wall [4].

In this study, there was no attempt to determine the relative contributions of the different image post-processing tools to the final diagnosis. To start with, each segment was evaluated at the axial images at the proper R-R interval, and then different post-processing techniques, including multi-planner and curved reformations, maximal intensity projection and volume rendering, some or all of them were employed in an integrated manner to reach the diagnosis.

The published studies revealed high negative predictive value and high specificity of CT coronary angiography. The high NPV means low false negative results and the high specificity means high true positive results. In other words; when a segment is interpreted as negative at CT (meaning normal or mildly atherosclerotic), it is unlikely to show significant stenotic lesion or occlusion at conventional angiographic examination, hence the CT angiography is a good negative test. The importance of this fact is to determine the potential role of the multislice CT angiography as a non-invasive tool for initial evaluation of the coronary system in patients with clinically moderate probability for coronary artery disease who show equivocal results at the stress-tests (stress ECG, stress perfusion scan and stress echo) before proceeding to the conventional (invasive) angiography. In such cases, negative CT examination would help the patient to avoid the unnecessary invasive test. The comparatively lower values for the positive predictive value are attributed to the relatively high incidence of the false positive results, meaning that some of the apparently significant lesions at CT may actually be not more than mild atherosclerotic plaques or even artifacts caused by dense calcification, metallic material (stent or clips) or respiratory/cardiac motion. The high false positive results at this study may be attributed to the tendency to appreciate rather than under-estimate coronary plaques in order not to miss lesions.

Lepor N.E. and Madyoon H. 2005 [19], stated that from their own experience using both the 16- and 64-slice CT scanners, they have observed an improved ability to obtain coronary artery images in patients that are hard to image (e.g. the obese, those unable to maintain long breath holds). These scanners have also proved useful in coronary arteries that are calcified or had metal stents placed within and in patients with faster heart rates. It is now clear that non-invasive CT angiography of the coronary arteries requires the use of, at minimum, the 16-slice scanner, with improved imaging observed with the 64-slice CT.

The significant improvement in sensitivity and specificity in studies using the 64-rather than the 16-slice scanners could be attributed to the reduced tube-rotation time (330ms instead of 420ms) with consequent improvement in the temporal resolution (165ms instead of 210ms). Another important factor is the improved spatial resolution owing to the use of the least available slice thickness (0.5 and 0.6mm instead of 0.75mm). However; the positive predictive value is still low with the 64-slice scanners. This, again, would be attributed to the tendency
to consider the coronary lesions whose CT interpretation was uncertain, resulting in a number of false-positive outcomes, rather than underestimating these lesions and thereby “missing” lesions, which may have serious consequences in a symptomatic patient population.

Coronary artery bypass grafts (CABG) are important issues being suitable for imaging with MSCT angiography. Patency or occlusion of grafts can be established by the presence or absence of contrast material within, respectively. Because of their relatively large size and less motion with heart beats; the grafts are generally better evaluated for the presence and severity of stenosis. Beam-hardening artifact from metallic surgical clips may obscure the adjacent portion of a bypass graft [4].

To evaluate the role of MSCT in assessment of the coronary bypass grafts, 20 performed a prospective comparison of MSCT with invasive coronary angiography in 65 patients with CABG, using a scanner able to acquire 4 parallel slices of the heart at 1-mm collimation. Accuracy of MSCT in the detection of occluded conduits was very high, with sensitivity and specificity rates of 97% and 98%, respectively; however, 38% of 124 patent grafts couldn’t be evaluated by MSCT angiography because of insufficient breath holding with respiratory motion artifacts (11 cases), arrhythmias (5 cases), poor opacification owing to improper amount or timing of contrast (7 cases), and metallic clips (17 cases). Within the limits of conduits judged evaluable, sensitivity and specificity in the detection of significant stenosis were 75% and 92%, respectively. When conduits judged unevaluable were included in the analysis, the overall accuracy for detection of stenoses was quite low, with a sensitivity of 48%.

In this study, the total number of examined patients with previous CABG surgery is 5 having a total number of 12 conduits with an average of 2 conduits per patient. In 4 of these conduits; the left internal mammary artery (LIMA) was used to enforce the blood supply in the left coronary system and in one case a RIMA was used, while the remaining 7 conduits were venous and arterial grafts. During their courses; all patent LIMA, venous and arterial grafts were correctly identified at the CT angiographic examinations.

In a study performed by Willmann J.K., et al., 2004 [11], the authors investigated the ability of the MSCT coronary angiographic examinations to assess the coronary stent patency as well as detection and quantification of the in-stent restenosis. They also tested the CT ability to accurately measure the in-stent luminal diameter. Nineteen patients with 26 coronary stents underwent ECG-gated CT angiography with a 16-detector row scanner 1-3 weeks after stent placement. CT images depicted the lumina of 20 stents in 14 patients. CT attenuation measured in the stented lumen was higher than the attenuation in the proximal and distal unstented lumen (owing to the beam-hardening artifacts by the metallic stents). Estimated values for in-stent luminal diameter were lower with CT than with conventional angiography. Finally; they concluded that the visualization of the in-stent lumen at CT angiography with a 16-detector row scanner allows assessment of coronary artery stent patency yet the accurate evaluation of the in-stent restenosis is quite challenging.

This study included 7 coronary stents. According to the angiographic findings; 5 stents were patent and two showed in-stent re-stenosis. All of the five patent stents were diagnosed at CT while the two cases of in-stent re-stenosis were successfully detected at CT.

A well-recognized limitation in the assessment of coronary stenosis with CT angiography is related
to dense coronary arterial calcification. The resulting "blooming" effect causes difficulties in assessing adjacent plaque structures and patent lumen, potentially resulting in a false-positive evaluation of stenosis (overestimation of the degree of narrowing) [4]. However, the presence of high calcium score itself has its own diagnostic value, identifying patients who may benefit from stress nuclear myocardial perfusion and conventional angiography to assist in detection of obstructive CAD [21]. In our study; all cases underwent coronary calcium score prior to CT angiography. Cases with high calcium score (1000 or more) were shifted directly to conventional angiography.

In a study done by Choi H.S., et al., 2004 [22] to identify artifacts and pitfalls that commonly degrade image quality and that could result in misinterpretation; CT coronary angiography using MSCT scanner with four detector rows in 110 consecutive patients were analyzed. The problems identified were classified into four broad categories: (A) Motion-related artifacts due to cardiac, respiratory $ or other body motions; (B) Beam-hardening effects caused by metallic implants, severe calcifications, or air bubbles in the pulmonary artery that obscured the underlying coronary arterial lumen; (C) Structural artifacts produced by adjacent contrast material-filled structures and overlying vessels; and (D) Artifacts that resulted from technical errors or limitations. The most frequently observed artifacts were those related to cardiac motion. The most effective methods for minimizing cardiac motion artifacts are pre-medication with B-blockers to maintain optimal heart rate during scanning and optimal selection of the reconstruction window.

In order to overcome these pitfalls; [23] recommended the usage of contrast agent with the highest iodine concentration available to improve the opacification of the smaller vessels and the proper visualization of the coronary side branches and collateral pathways [16]. Stated that the choice of a proper reconstruction window for each coronary artery is the key factor for reliable evaluation of the coronary lesions in CT studies, which was also pointed out by Zhang S.Z., et al., 2005, Hamoir X.L. et al., [24,25].

Radiation dose:

Radiation exposure at cardiac CT has received special attention recently, particularly, in light of the current and potentially expanding future use of this modality as a screening tool for CAD in apparently healthy asymptomatic individuals. Relatively high radiation exposure occurs with retrospectively ECG-gated cardiac CT because of continuous X-ray exposure and overlapping data acquisition at a slow table feed. However, the radiation dose at retrospectively ECG-gated cardiac CT can be substantially reduced by means of reduction of tube output in each cardiac cycle during phases that are of less importance for image reconstruction i.e. systole "ECG-gated dose modulation" [26].

Pitfalls and artifacts in multislice CT coronary angiography:

Various artifacts can degrade image quality at CT coronary angiography. Artifacts at CT angiography included cardiac pulsation, rhythm disorders, respiratory issues, partial volume averaging effect; high attenuation entities, inappropriate scan pitch, contrast material enhancement and patient body habits are important factors hampering accurate diagnosis [27].

Rhythm disorders involve apparent arrhythmia such as atrial fibrillation of recent technical advances, reliable coronary imaging can be performed only in patients with normal sinus rhythm at the time of examination. Even in these patients, however alteration of the heart rate during data scan creates data sets in a slightly different cardiac cycle, leading to a section gap and coronary pseudostenosis [13].

Section gaps exaggerate the rapid moving segment and higher heart rate, although a significant heart rate increase leading to a section gap cannot be determined, the association of section gaps and heart rate increase is frequently recognized. Non-assessable segments are frequently observed in arrhythmia, although successful coronary CT angiography can be performed even in atrial fibrillation, when the average heart rate is very low. Apparent multiple section gaps in imaging data sets are called banding artifacts. Banding artifacts are observed even in motion free imaging data sets. The most frequent causes of banding artifacts are arrhythmia, no breath hold, and alteration in heart rate during acquisition. However, the occurrence of banding artifacts cannot be predicted prior to scanning in most cases. Long acquisition time is associated with increased frequency of alteration in heart rate during data acquisition. Thus 16-detector row CT, with its fast scanning capability, reduces the prevalence and degree of alterations in heart rate data acquisition [27].

Motion artifacts other than those from cardiac motion result either from respiratory or voluntary motions that is generally preventable with careful instruction of the patient. Artifacts caused by
The most commonly encountered beam hardening and structure related artifacts are those produced by surgically implanted high attenuating materials or by contrast enhancement in natural structures. Beam hardening effects are usually caused by metallic objects such as clips, markers, and wires used in coronary artery bypass surgery or by coronary stents, but they may also be caused by naturally occurring coronary calcifications. The use of nonmetallic surgical materials also helps to ensure the accuracy of coronary bypass graft with multi-detector row CT. The nature and extent of artifacts caused by intra-coronary stents depend largely on the material of which the stent is made, the lumen visibility varies depending on the type of stent; stent made of or coated with gold causes the most severe artifacts [28].

Both high and low-attenuating artifacts may be exacerbated by motion or by inappropriate selection of the reconstruction, or they may be minimized with reduced motion and optimal reconstruction window. Any negative effects of beam hardening or structure-related artifacts on the accuracy of image interpretation can be avoided with a review of axial source images [30].

Artifacts that result from technical errors in image data acquisition and interpretation may be avoided with appropriate planning and execution of the scanning procedure, including instruction and practice of the patient in breath holding, as well as the optimal selection of anatomic coverage, scanning delay, pitch, and reconstruction window. To improve interpretations, it is essential to use reconstructions tailored to each case. Insufficient anatomic coverage in the evaluation of bypass grafts can be avoided with an awareness of surgical records and with scout imaging of the entire thorax to determine the area that should be included in CT angiography. Inaccurate estimation of the circulation time, which may result in a useless study, can be easily avoided with a 5-second scanning delay after peak enhancement of the aorta, because graft vessels enhance later than do native coronary arteries. Artifacts that are related to flow dynamics also limit the usefulness of multi-detector row CT coronary angiography. Because multi-detector row CT coronary angiography does not depict the temporal course of contrast enhancement, it cannot be used to detect sluggish retrograde, or antegrade flow. Competitive flow in a coronary artery bypass graft has been reported as an important cause of graft failure, particularly in bypass grafts that are connected to a moderately stenotic coronary artery [31].

References


