Computed tomography coronary angiography: what is the hype, the reality, and the future?

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The number of computed tomography (CT) scanners capable of imaging the coronary arteries is increasing exponentially in the Western world. Expectations are that CT coronary angiography (CTCA) will replace conventional angiography in many patients. However, there is hardly any evidence showing that multislice CT is better than conventional stress testing in selecting patients for coronary interventions. The high negative predictive value of CTCA may provide help for some patients who are very concerned about the presence of coronary artery disease. Chest pain, however, may be caused by myocarditis and coronary vasospasm and CTCA is not able to exclude these conditions. The future will show whether CTCA is able to depict the development of atherosclerosis in the arterial wall by serial examinations at a reduced radiation exposure.

Keywords: multislice computed tomography; noninvasive coronary angiography; coronary artery disease; coronary vasospasm; plaque imaging; invasive coronary angiography; risk stratification

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Patients and doctors are often fascinated by the same concepts. They both want to learn more about the future and make prophecies about the patients' individual path in this direction. Both are also fascinated by pretty pictures showing the patients' inner self, hopefully providing the ultimate evidence that the patients are healthy and that their symptoms do not indicate an ominous outcome. The desire to predict the future and the belief that medical imaging can be helpful in this respect led to an explosion of the number of imaging services all over the world, notably in the US. Modern computed tomography (CT) holds the promise to image the coronary arteries noninvasively. Expectations are great, but what is the reality? What does the future hold?

THE HYPE

The number of CT-scanners capable of imaging the coronary arteries is increasing at an exponential growth in the Western world. Membership in the Society of Cardiovascular Computed Tomography (SCCT) is rapidly growing and now exceeds 2200 with 15 to 20 new applications being received daily. The Society was only founded in March 2005. The public is flooded with predictions that CT angiography will take the place of single photon emission computed tomography (SPECT) and cardiac catheterization for the majority of clinically important cardiac disorders. Indeed, 72% of US cardiologists order CT angiography procedures every month and many cardiologists plan to purchase the CT equipment necessary for performing this examination for their own practice. The SCCT as well as other interest groups are pushing hard for Medicare reimbursement for the procedure and experts predict that nationwide reimbursement will emerge by 2008 at the latest. An estimate for local Medicare reimbursement in the US is between $400 and $600. The promise made to Medicare is that CT coronary angiography (CTCA) will save the patient an unnecessary and more costly invasive cardiac catheterization procedure. The question of whether looking at the coronaries of so many people makes any sense is never asked.

The prospect of being able to noninvasively have a look at the coronary arteries motivates radiologists and cardiologists to line up for learning CTCA. However, few physicians have accumulated enough experience to competently perform this procedure. Fewer still are qual-

SELECTED ABBREVIATIONS AND ACRONYMS

CTCA	computed tomography coronary angiography
MSCT	multislice computed tomography

ified to teach physicians how to conduct and interpret examinations. The American College of Cardiology Foundation/American Heart Association (ACCF/AHA) clinical competency statement requires 150 supervised cases. These include 50 cases in which a physician is directly involved in scanning to establish skill in interpreting a coronary artery CT scan. In contrast, the American College of Radiology requires board-certified radiologists to perform only 75 supervised scans to achieve competence. This difference recognizes the training in thoracic CT interpretation that radiologists receive during their residencies. There are, however, also warning voices such as that of Dr Pamela Douglas, the outgoing ACC President. “If imaging were a drug, approval would be denied” she said at the opening of the 55th Annual Scientific Session of the American College of Cardiology in 2006 speaking of problems with cardiovascular imaging research. “New diagnostic tools and creative treatments have sparked an exciting evolution in medicine,” she said. Her warning, however, was: “While this would seem to be a positive change, sometimes we adopt these new tools with not enough thought to ensuring quality.” Despite this call for diligence and patience, requirements for cardiology fellowship education were already changed and now include at least one month of cardiac CT applications. CTCA advocates argue that this is necessary as cardiac CT is becoming integral to cardiology practice. Despite the fact that randomized multicenter trials remain the basis for evidence-based medicine and that such studies are conspicuously absent, many radiologists and cardiologists embrace cardiac CT as the new standard of care for patients at intermediate risk for the development of an acute coronary syndrome. Some already see CTCA in the emergency room to immediately define the status of the coronaries. Pilot studies show that cardiac CT speeds diagnosis and hence allows for earlier discharge of patients at intermediate or low risk for myocardial infarction.[1] The market is huge, as approximately 3 million patients report to emergency rooms with chest pain every year. Excitement over the 64-slice scanners has not yet subsided and already new technology is available: dual source CT will extend the applicability of CTCA to larger patient groups such as those with faster heart rates or rhythm disturbances like atrial fibrillation, avoiding the current obligatory use of β-blockers to slow down the heart rate. High heart rates are detrimental to image quality with current 16- to 64-slice scanners and lead to blurring and artifact generation.[2] Recent findings indicate that heart rate is predictive of image quality and that a low heart rate substantially improves vessel visibility and stenosis detection.[3,4]

Why all the excitement? Calcium-scoring of the coronary arteries has been around for many years. Although more and more solid data are gathered by clinical researchers that indicate that quantification of coronary calcium provides increased prognostic ability to predict cardiovascular events beyond and independent of traditional coronary risk factors, calcium-scoring has not ignited the imagination of patients and physicians. The breakthrough for cardiac CT came with the availability of 4-slice helical CT-systems, which were introduced in the year 2000. These systems showed the coronary artery lumen after intravenous injection of contrast material, but were limited in many patients because of image artifacts.[5] Yet, the possibility of visualizing the coronaries without inserting an arterial catheter quickly exerted a strong fascination on physicians and engineers, leading to rapid improvements in CT technology over the following years. Only 4 years after the introduction of the 4-slice system, systems offering 64 slices became available. These systems have shorter gantry rotation times, higher slice collimation, and higher tube output, all of which improve the temporal and spatial resolution of the machines. The number of slices itself is just helpful for shortening imaging times. Sixty-four–slice machines now permit coronary imaging within a breath-hold of approximately 6 seconds. The result is a stack of about 300 cross-sectional images with a slice thickness of between 1/2 and 1 millimeter. Three-dimensional reconstructions of the coronary arteries often in color attract the attention of radiologists, cardiologists, cardiac surgeons, and general practitioners alike. And all this beauty comes without hospital stay, without catheters inserted into the body, and without heaps of consent forms to be signed informing the patient about the risk of death and myocardial infarction as is the case with invasive cardiac catheterization.

Of course, CT exposes the patient to about 3 times more radiation than conventional coronary angiography (for multislice CT [MSCT] angiography effective dose [ED] 14 mSv and for conventional coronary angiography ED 6 mSv) although estimates differ considerably.[6,7] These exposures yield lifetime risks of 0.07% and 0.02%, respectively, of inducing a fatal cancer in the general (ie, age- and gender-averaged) population. However, CT proponents point to the fact that conventional coronary angiography poses additional serious risks associated with cardiac catheterization, yielding a nonradiogenic risk of mortality—exclud-

	N	Sensitivity	Specificity	Positive predictive value	Negative predictive value
Leschka et al,[8] 2005	53	100	100	100	100
Raff et al,[9] 2005	70	95	90	93	93
Leber et al,[10] 2005	59	94	-	-	-
Mollet et al,[11] 2005	52	100	92	97	100
Ropers et al,[12] 2006	82	96	91	83	98
Ghostine et al,[13] 2006	66	97	95	93	97
Ropers et al,[14] 2006	50	95	86	90	92

Table I. *Accuracy of 64-slice computed tomography in identifying patients with at least one coronary artery stenosis.*

ing contrast media reactions—of 0.11%. The argument continues that combining the radiogenic and nonradiogenic risks (0.02% and 0.11%, respectively) yields a 0.13% overall risk of mortality from conventional coronary angiography—nearly 2-fold higher than that for MSCT angiography (0.07%). If one were to use the lower, more age-appropriate risk factors for the older patient population in question, the radiogenic risks of both conventional coronary angiography and MSCT would be reduced by about half, further widening the overall safety ratio of MSCT relative to conventional coronary angiography, by a factor of nearly 2 in favor of MSCT.[8]

If that is not enough to convince you, consider the following: some believe that widespread use of this "soft and safe" new CT tool could even save huge numbers of lives. This interesting argument goes as follows: if the entire 18 800 000 people comprising the 50- to 55-year-old population of the US were screened for coronary artery disease using MSCT, the anticipated increase in the number of fatal cancers would be 14 900. If this screening were repeated every 5 years until the population reached the age of 70, the aggregate increased risk would be increased by approximately 3-fold, to 42 900. Because the average age of patients with their first infarction is 65.8 for men and 70.4 for women and because 94% of patients have >75% stenosis in at least one vessel, these sequential procedures should identify patients with significant stenoses before their initial event. Hence, if this procedure prevented even 10% of the estimated 355 000 sudden deaths each year, the proponents of MSCT feel the trade-off would be well worthwhile.[8] At this point, however, it appears necessary to mention the robust data demonstrating the low predictive value of stenosis severity for the probability of vessel occlusion at the site of the stenosis.[9]

Now we understand the fascination of MSCT coronary angiography: beautiful, easily obtained images of coronary artery stenoses, which otherwise would go undetected, provide the opportunity to intervene early enough and put an end to sudden death. One just has to perform enough MSCT coronary angiograms. We will deal later with the fallacy of these arguments.

THE REALITY

Where—at this point in time—is the appropriate position of MSCT in the armamentarium of the clinical cardiologist who has to deal with the expectations and the fears of those suffering from coronary artery disease or at risk of developing the disease? When appropriately performed in appropriately selected patients, 64-slice CTCA will result in sensitivities between 86% and 99% and specificities of 93% to 97% for detecting stenoses considered significant by conventional coronary angiography *(Table I).*[10-16] However, one has to remember that 9% of vessel segments with a diameter >1.5 mm evidenced by conventional coronary angiography cannot be evaluated by 64-slice CTCA due to degraded image quality. An important asset of the technique, hailed by all proponents, is the high negative predictive value of between 95% and 99%.[17] The values given represent the accuracy data if per segment or per artery analysis were performed. For a patient-based analysis, CTCA is even better with sensitivity values of between 94% and 100% and specificities ranging from 90% to 100% *(Table I).* The negative predictive value for the patient-based analysis is between 93% and 100% for the 64-slice scanners. However, data are still preliminary and the studies published today incorporated a maximum of 134 participants.

The only multicenter study[18] published employed the now outdated 16-slice CT technology, but some important caveats can nevertheless be derived from this publication. It has been well known that coronary artery calcifications pose substantial obstacles to the correct interpretation of CTCA scans.[19] Blooming effects expand the apparent size of calcified plaques and hence lead to overestimation of plaque volume, resulting in false-positive diagnoses. This is of course well known to experienced CT interpreters. In order to preserve their high negative predictive value they tend to overrate such scans and misinterpret calcifications as stenoses rather than risk missing a stenosis. Although blooming effects have become less important with the higher spatial resolution of newer machines, they continue to be a source of artifacts even with the latest scanner generation *(Figures 1 and 2).* It has hence become customary in experienced centers to first perform a low-dose radiation nonenhanced MSCT scan to evaluate coronary calcium and omit CTCA if the Agatston-score is more than 600. However, some believe that, with dual-source CT, CTCA can be reliably performed in patients with calcium scores up to 1000. In the study of Garcia et al,[18] only 201 patients (84%) had Agatston scores <600 and were thus evaluated by MSCT angiography. However, there were additional problems with the procedure leading to further exclusions. Two patients had arrhythmias that were missed at the initial screening procedure. Stented segments were excluded from analysis because stents carry similar problems as severe calcifications *(Figure 3).* There was also a large number of nonevaluable segments by MSCT (29%) due to respiratory or cardiac motion or excessive calcification, poor opacification, or small vessel size. Hence, after censoring all nonevaluable segments as positive, the sensitivity for detecting more than 50% luminal stenoses was 89%, with a specificity of only 65%. The positive predictive value was 13%, but the negative predictive value remained high at 99%—albeit at the cost of an unacceptably low predictive value. In a patient-based analysis, which is the clinically more important analysis compared with segmental analysis, the sensitivity for detecting patients with at least one narrow segment was 98%, with a specificity of 54%. This study indicates that in order to preserve an attractive negative predictive value, a very high number of false positives need to be accepted when MSCT coronary angiography is performed with 16-row-scanners. Even though

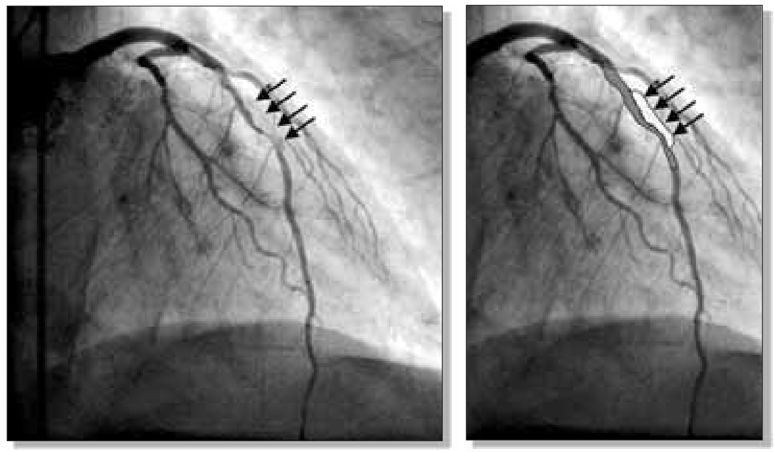

Figure 1. *Conventional coronary angiogram in a patient with typical angina. There is a large eccentric calcification next to the severely stenosed left anterior descending coronary artery (grey shadow indicated by black arrows). This is shown as a diagram in the right hand panel. The calcification is the white structure indicated by arrows.*

Figure 2. *Calcified left anterior descending (LAD) coronary artery stenosis. Same patient as in Figure 1. The dual-source computed tomography coronary angiography (CTCA) image* ***(right panel)*** *shows the first diagonal branch (white arrow) with a calcification at its take-off from the LAD, mimicking an ostial stenosis. The septal branch (dashed black arrow on the conventional angiogram* ***(left panel)*** *and white on the multislice computed tomography (MSCT)* ***(right panel)*** *seems to take off from a subtotal LAD stenosis in the CT image. However, the conventional angiogram does not show a stenosis at this level. The stenosis in the conventional angiogram is marked by the short black arrow. This stenosis is not well depicted due to the presence of calcification. Interestingly, the bulky calcification adjacent to the vessel is not shown on the CT images.*

Dual source MSCT images kindly provided by by Dr Anja Reimann and Prof Stephen Schröder, University of Tübingen, Germany.

appropriate tube current modulation led to a relatively low radiation exposure of 8±2.5 ms, this radiation burden is still higher than for conventional coronary angiography plus left ventricle angiography.[6,7] The authors conclude that routine implementation of CTCA in clinical practice is not justified. They feel, however, that CTCA is of potential use in excluding coronary artery disease in selected patients in whom false-positive or inconclusive stress test results are suspected.

The discussion on when to use MSCT in clinical practice is still greatly influenced by the belief that imaging of coronary artery anatomy is of greater clinical value[8] than functional assessment of the consequences of impaired coronary blood flow. It is surprising that this superstition continues to influence scientific statements because a wealth of robust data showing the contrary is available.[20] When does it make sense to examine the coronary arteries? In order to approach this question it is useful to look at the recommendations for performing conventional coronary angiography issued by the ACC/AHA.[21] There are few Class I recommendations. One is for patients with severe grades of angina despite intensive medical treatment. The other Class I indication is for patients who, regardless of angina severity, are at high risk for severe ischemia or sudden cardiac death according to noninvasive functional testing. In these patients, coronary angiography makes sense because there is a high probability that high-grade coronary lesions will be detected, resulting in appropriate revascularization. In contrast, patients with mild symptoms or atypical symptoms do not need coronary angiography because this test does not provide any additional prognostic or therapeutic benefit.

Let us briefly have a look at the prognostic implications of coronary angiography in asymptomatic or mildly symptomatic patients. Usually, prognosis is estimated on the basis of conventional risk factors, but calcium-scoring by MSCT may further improve risk stratification in these patients.[22] Coronary angiography can only provide additional information about the severity of stenosis in patients who would already be known to have coronary artery disease by calcium scoring. The low predictive value of stenosis severity for the probability of vessel occlusion at the site of the stenosis, however, has been amply documented.[9] On the other hand, in those who by risk factor analysis and/or CT-calcium scoring are already known to be at low risk, coronary angiography could just confirm this by excluding the presence of coronary artery stenosis. What about the intermediate-risk group? The guidelines recommend noninvasive tests rather than invasive coronary angiography because the posttest probability after these tests may help to decide whether or not to use invasive coronary angiography.[21] Do these recommendations still hold true when noninvasive coronary angiography by MSCT is broadly available? Some claim that the additional dye load and radiation exposure of MSCT argue against the broad use of this new technique in intermediate-risk patients.[23] If many patients need invasive coronary angiography following a positive MSCT result, patients would unnecessarily be exposed to the same risks twice. As invasive coronary angiography is not recommended in patients with a low pretest probability of significant coronary artery disease and MSCT coronary angiography is not likely to alter the statistically good prognosis in this patient group, where could be the place for MSCT coronary angiography in the prognostication of patients with coronary artery disease? If the pretest probability of coronary artery disease is less than 50%, a negative result on MSCT coronary angiography is associated with a posttest probability of coronary artery disease below 10%.[24] In order to achieve a posttest probability below 5% by a

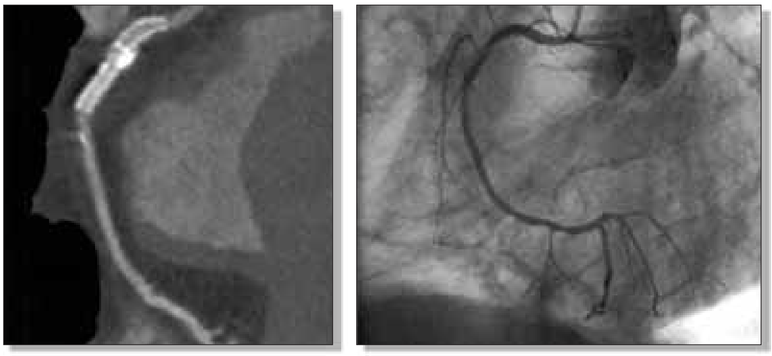

Figure 3. Left: *Dual source computed tomography coronary angiography (CTCA) of right coronary artery (RCA) with proximal stent. Some narrowing seems to be present in the proximal portion of the stent, but this is not confirmed at conventional angiography* ***(right).*** *There is some artifact in the CTCA image within the mid-portion of the stent, which makes the stent not assessable by multislice computed tomography (MSCT). The result after stenting is satisfactory as assessed by conventional coronary angiography.*

Dual source CT image kindly provided by Dr Anja Reimann and Prof Stephen Schröder, University of Tübingen.

negative MSCT, the pretest probability needs to be below 30%. This would be the case in a person with nonspecific chest pain and equivocal results of functional noninvasive testing. Excluding coronary artery disease would be important in such a patient if the patient's symptoms require multiple hospitalizations. In fact, such patients constitute a significant subgroup of those undergoing coronary angiography in countries with easy access to invasive coronary angiography as in Germany. The main benefit for such a patient with a low pretest probability in whom the response to treatment or other noninvasive tests is inconclusive, is that he will be reassured if MSCT results are negative. Based on this negative MSCT, the patient might then not be sent by his or her physician who is also anxious to not miss a disease with potential fatal consequences to invasive coronary angiography.

But is the exclusion of coronary stenoses by MSCT really helpful when the chest pain symptoms described by the patient sound like real angina, when they occur mainly at rest or both at rest and with exercise? Will patients really be content if the physician tells them that their symptoms are completely innocent and that there is no heart disease? Is it not the obligation of the patient's doctor to find an explanation for the patient's symptoms especially when the patient frequently contacts other physicians or emergency facilities and is even hospitalized? Aren't there alternative explanations for chest pain symptoms in patients known to be reliable historians to their general practitioners? Chest pain at rest is frequently associated with regional myocardial inflammation as demonstrated by late gadolinium enhancement cardiac magnetic resonance imaging. Coronary vasospasm is another almost completely forgotten cause of chest pain. Among patients who had acute coronary syndromes with hospital admission severe enough to warrant immediate coronary angiography, 20% to 30% have no coronary stenosis. Even among those with evidence of myocardial necrosis by troponin elevation, 6% have no significant angiographic coronary stenosis.[25] Coronary vasospasm is present in 50% of patients presenting with acute coronary syndromes, but normal or near-normal coronary angiograms.[26] Vasospasm as the cause of a patient's chest pain can be confirmed by invasive coronary angiography. In a patient with stress-induced angina or more commonly repeated episodes of resting angina, the injection of acetylcholine following exclusion of significant coronary artery disease often results in coronary vasospasm with reproduction of the patient's symptoms.[27] This test can be performed during conventional coronary angiography at negligible additional risk when acetylcholine is infused slowly with increasing concentrations. Vasospasm is quickly and safely reverted by intracoronary injection of nitroglycerine. Similar testing cannot be performed using MSCT coronary angiography. Hence, even in patients with a low probability of coronary artery disease and inconclusive results at noninvasive testing, MSCT coronary angiography is inferior to invasive coronary angiography for making a definitive diagnosis in patients who often suffer from severe and repetitive symptoms *(Figure 4)*.

If MSCT coronary angiography is not helpful to improve prognosis, would it not be a suitable tool to select the low-risk patient who might benefit from a coronary intervention? Unfortunately, all available data indicate that coronary interventions in patients with mild stable angina do not improve outcome. Patients with severe angina, however, should undergo *invasive* coronary angiography to give them the opportunity of immediate percutaneous coronary interventions.

THE FUTURE

Even with the recently introduced 64-slice CT systems, motion artifacts remain the most important challenge for CTCA. Even with 64-slice CT, the administration of β-blocking agents and nitroglycerine is necessary to provide acceptable image quality in many patients. In order to achieve temporal resolutions of less than 100 ms, which would eliminate the need for heart-rate control, new concepts are necessary. Multisegment reconstruction approaches from imaging over various cardiac cycles give variable results and are not robust enough for standard clinical performance. Although electron beam CT (EBCT) provides short scan times, its spatial resolution and signal-to-noise ratio in larger patients is insufficient for state-of-the-art cardiac imaging or for general radiology applications. Shorter imaging times could be achieved by shorter rotation times of the currently available mechanical scanners. However, mechanical forces with current scanners providing 330 ms rotation time are already at 28G and these forces would increase to more than 75G at rotation times of less than 200 ms. Therefore, a new dual-source CT system was developed, which is equipped with two x-ray tubes and two corresponding detectors. The two acquisition systems are mounted onto the rotating gantry with an angular offset of 90 degrees. Each detector comprises 40 detector rows, the 32 center rows have an 0.6-mm collimated slice. Using the z-flying focal spot technique two subsequent 32-slice readings are

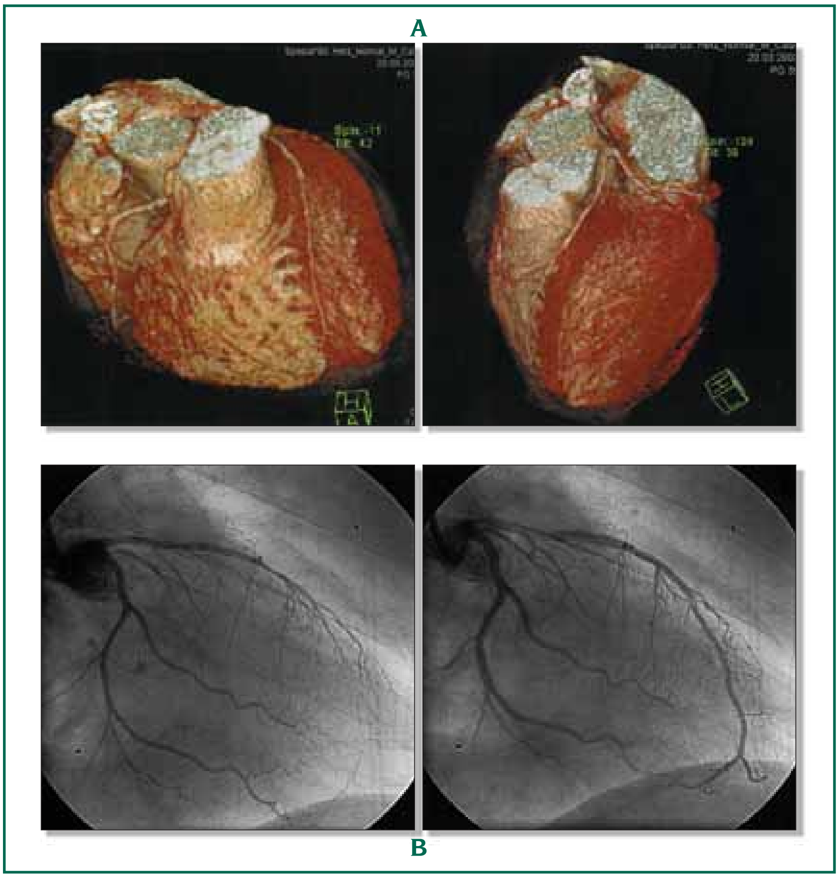

Figure 4. A: *Exclusion of significant coronary stenoses by 3-D MSCT reconstruction: 16-slice multislice computed tomography (MSCT) 3-dimensional reconstruction of coronary arteries of a patient with repetitive attacks of resting angina. Exercise tests were repeatedly normal. The CT does not show significant coronary artery disease.* ***B:*** *Left anterior descending (LAD) coronary artery vasospam.* ***Left:*** *when 100 µg acetylcholine is selectively infused into the LAD, the patient experienced identical symptoms as those that brought him into the hospital, and subtotal occlusion of the distal LAD was observed.* ***Right:*** *After injection of 0.2 mg nitroglycerin (NTG), the vessel opened wide and the symptoms disappeared immediately.*

combined to one 64-slice projection. The key benefit of dual source CT for cardiac scanning is improved temporary resolution. The scanner provides temporary resolution of approximately one fourth of the gantry rotation time, which is approximately 83 ms. As the system can cover almost 30 cm in the longitudinal direction, data from one cardiac cycle only are necessary to reconstruct the images.[28] Initial experience with this system shows that high-quality images can be obtained without the use of β-blockade.[28] Image quality is further improved due to the short temporal resolution, which avoids the blur of motion artifacts. The improved temporal resolution may allow the time window during which the full x-ray tube current is used to be shortened. Without such measures the radiation dose is even further increased with the new dual-source CT as compared with the 64-slice CT.

Although MSCT coronary angiography is not suitable for replacing invasive coronary angiography or noninvasive tests for the detection of ischemia on a broad basis, we have not yet fully explored the possibilities of this fascinating and rapidly developing technology. There are interesting niche applications such as the preoperative evaluation of patients with valvular heart disease where MSCT coronary angiography may play a clinical role. Although no large-scale clinical trial has assessed the contribution of coronary angiography, this invasive investigation is recommended in the preoperative assessment of patients with valvular heart disease.[21] A limiting factor to the widespread use of MSCT-coronary angiography is the presence of high calcium scores in the patients with aortic stenosis, but three fourths of these patients may have calcium scores low enough to permit reliable exclusion of coronary artery disease by MSCT.[29] Hence, the use of MSCT may in the future help to avoid conventional coronary angiography in up to 80% of patients with aortic stenosis. With improved temporal resolution MSCT coronary angiography may also become useful in patients with mitral valve disease who frequently suffer from atrial arrhythmias. This currently precludes reliable coronary imaging with 64-slice MSCT. With the more widespread availability of dual-source CT patients with mitral valve incompetence might be even more suitable than those with aortic stenosis because they usually have less coronary calcification.[30]

Patients with left bundle-branch block pose serious problems to noninvasive stress testing. False-positive results are common with myocardial perfusion scintigraphy, but the abnormal motion of the interventricular septum also makes dobutamine stress echocardiography a challenge. However, it is important to identify the underlying cardiac pathology as it primarily determines prognosis. MSCT may become an interesting modality in the management of these patients. It detects significant coronary artery stenoses with excellent accuracy and identifies 95% of patients without significant stenosis and 97%

Table II. *Indications for computed tomography coronary angiography considered to be appropriate by the American College of Cardiology Foundation (ACCF) Task Force.[32] Assume the logical operator between each variable listed for an indication is "AND."*
Abbreviations: *CAD, coronary artery disease.*

1. Detection of CAD in symptomatic patients
- Evaluation of chest pain syndrome
- Intermediate pretest probability of CAD
- ECG uninterpretable *or* unable to exercise

2. Detection of CAD in symptomatic patients
- Evaluation of suspected coronary anomalies

3. Detection of CAD in symptomatic patients
- Acute chest pain
- Intermediate pretest probability of CAD
- No ECG-changes and serial enzymes negative

4. Detection of CAD with prior test results
- Evaluation of chest pain syndrome
- Uninterpretable or equivocal stress test (exercise, perfusion, or stress echo)

5. Assessment of morphology
- Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels and cardiac chambers and valves
- Evaluation of coronary arteries in patients with new-onset heart failure to assess etiology

with significant stenosis by conventional coronary angiography.[15] Other new and exciting possibilities provided by MSCT are the visualization of nonstenotic plaque including noncalcified soft plaque. This opens a fascinating window to the serial study of the development of atherosclerosis, ie, in patients with a high genetic risk. However, the excitement raised by this new possibility of noninvasive study of the development of atherosclerosis must be tempered when thinking of the radiation burden resulting from serial studies. MSCT may also offer the possibility to differentiate between fibrous and lipid-rich plaques on the basis of differences in the attenuation values measured in Hounsfield units.

Although there are interesting new applications in difficult clinical situations, the availability of MSCT coronary angiography also poses significant challenges to the medical community. Rates of invasive testing and treatment of coronary artery disease nearly doubled from 1993 to 2001. However, hospitalization rates for acute myocardial infarction remained stable over that period. The well-known differences in rates of cardiac testing and treatment between nonblack men and other subgroups persisted over time. Hence, temporal increases in the use of noninvasive and invasive car-

Table III. *Indications for computed tomography coronary angiography considered to be inappropriate by the American College of Cardiology Foundation (ACCF) Task Force.[32] Assume the logical operator between each variable listed for an indication is "AND."*
Abbreviations: *CABG, coronary artery bypass grafting; CAD, coronary artery disease; CHD, coronary heart disease; PCI, percutaneous coronary intervention.*

1. Detection of CAD in symptomatic patients
- Evaluation of chest pain syndrome
- High pretest probability of CHD

2. Detection of CAD in symptomatic patients
- Acute chest pain, and
- high pretest probability of CHD
- ECG-ST-segment elevation and/or positive cardiac enzymes

3. Detection of CAD in asymptomatic patients
- Low CHD risk by Framingham risk criteria

or
- Moderate CHD-risk by Framingham risk criteria

4. Detection of CAD with prior test results
- Evaluation of chest pain syndrome
- Evidence of moderate to severe ischemia on stress test (exercise, perfusion, or stress echo)

5. Risk assessment with prior test results in asymptomatic patients
- High CHD-risk (Framingham)
- Within 2 years prior cardiac CT angiogram or invasive angiogram without significant obstructive disease

or
- High CHD risk (Framingham)
- Prior calcium score ≥400

6. Risk assessment: preoperative evaluation for noncardiac surgery
- Low-risk surgery
- Intermediate perioperative risk

7. Detection of CHD: post revascularization (PCI or CABG) in asymptomatic patients
- Evaluation of bypass grafts and coronary anatomy
- <5 years after CABG

or
- Evaluation of bypass grafts and coronary anatomy
- ≥5 years after CABG

or
- Evaluation for in-stent restenosis and coronary anatomy after PCI

diac services could not be explained by changes in disease prevalence and did not succeed in narrowing preexisting treatment differences. One also has to remember that such increases, although bringing benefit to some, will expose others to risk and cost without appropriate benefit.[31] The Foundation of the American College of Cardiology has responded to the rapid and uncontrolled increase of medical imaging procedures by defining appropriateness criteria for cardiac computed tomography. *Table II*[32] lists indications that are currently viewed as appropriate for performing CT angiography. However, the panel also defined clinical situations where the performance of a CT-angiogram is considered to be inappropriate *(Table III)*.[32]

SUMMARY

MSCT coronary angiography is a fascinating new technical tool that has not yet found a definite place in clinical cardiology. It is certainly premature to speculate that this new noninvasive technique will replace invasive coronary angiography. If indeed too many invasive coronary angiograms were currently performed it does not follow that we should replace them by even more noninvasive coronary angiograms. The possibility to get excellent images of the coronaries including the plaques surrounding their lumen without the need to stab holes in the femoral arteries and insert catheters into the ostia of the coronary arteries should not seduce us into an indiscriminate use of this new technique. Looking at the coronaries will not solve the main medical problems associated with coronary artery disease: the suboptimal use of preventive measures and the suboptimal allocation of medical resources to those who need it most.

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