Multidetector-Row Computed Tomography to Detect Coronary Artery Disease:
The Importance of Heart Rate

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DEAR COLLEAGUE,

During the past decade, we have seen rapid advances in noninvasive cardiac imaging technology, particularly in multidetector-row computed tomography (MDCT). MDCT allows the 3-dimensional visualization of bodily organs, and is routinely used to diagnose structural pathologies in the chest, abdomen, and head.

Optimizing MDCT for examination of the coronary arteries has been a particular challenge because of the nonlinear motion of the arteries, their small size, and their positioning. However, many technical difficulties have been overcome, and MDCT is emerging as a viable alternative for assessing coronary artery disease.

The purpose of this monograph is to present the latest advances in MDCT technology for imaging coronary arteries, and to consider approaches—such as managing heart rate—that optimize the usefulness of this technology.

I hope that you find this information helpful to you and your patients.

With best wishes for your continued success,

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NEEDS ASSESSMENT

Coronary artery disease (CAD) is the leading cause of death in the Western world. Traditionally, diagnostic imaging to identify the patients at high risk of cardiovascular events is performed invasively via coronary angiography. However, adverse events may occur, and 20% of angiography procedures do not require the co-performance of interventional procedures. Over the past few decades, noninvasive imaging technology has improved dramatically with the development of MRI and multidetector-row computer tomography (MDCT).

MDCT, especially in the newer 16- to 64-slice MDCT scanners, is capable of producing high-resolution 3-dimensional images of the heart for visualization of the coronary arteries. It can provide information not available from traditional angiography, such as characterization of plaques based on their content of lipid or fibrous material. Furthermore, data from a single MDCT scan can simultaneously provide information on the condition of the coronary arteries, aorta, and pulmonary arteries, rapidly investigating important causes of chest pain.

Because MDCT may eventually provide important benefits for cardiologists and their patients, it is important that cardiologists be aware of recent advances in this technology. The purpose of this monograph is to educate physicians in the theory behind MDCT, its strengths and limitations, and approaches to optimizing image quality, which include regulation of heart rate and appropriate use of contrast media.

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TARGET AUDIENCE

This continuing education program was designed to meet the educational needs of cardiologists, radiologists, and other health care professionals who treat patients with CAD.

LEARNING OBJECTIVES

After reviewing this monograph, participants should be able to:

1. Discuss the potential advantages of noninvasive imaging of coronary arteries.
2. Summarize recent technological advances in MDCT angiography.
3. Describe solutions for reducing heart motion-caused image artifacts in MDCT angiography.
4. Review the importance of contrast media in optimizing the quality of MDCT images.

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Disclosure is requested when faculty members are confirmed. This educational activity may include discussion of an unlabeled use or an investigative use not yet approved for a commercial product. Therefore, it is incumbent on individuals participating in this activity to be aware of these factors in interpreting its contents and evaluating its recommendations. Every effort has been made to encourage faculty to disclose any commercial relationships or personal benefits that may be associated with their participation in this program. The following indicates the faculty and nature of their commercial relationships.

Dr Fishman reports that he is on the advisory boards of GE Healthcare and Siemens Medical Solutions. He also receives grant support from both companies for educational activities at Johns Hopkins Hospital.

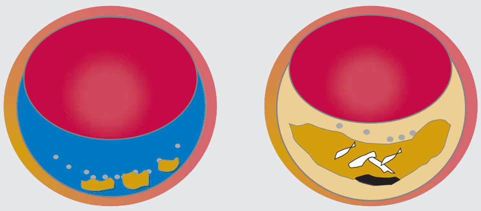
This activity includes a discussion of investigative use of MDCT, which is not approved for coronary angiography.

INTRODUCTION

Atherosclerosis resulting in coronary heart disease is the single leading cause of death in the United States.[1] Atherosclerosis is a heterogeneous disease that can manifest as stable fibrous lesions, unstable lipid-rich lesions, or mixtures of both in the vessel wall. Plaque composition is an essential predictor of plaque rupture and acute clinical complications.[2] Atheromas with areas of extracellular lipid and necrotic cores under a fibrous cap are most likely to cause death **(Figure 1)**.[2] Because >50% of patients die from coronary heart disease within hours of symptom onset,[1] early detection of unstable plaques followed by aggressive risk-reduction therapy to prevent events appears to be the ideal therapeutic approach.

During the past few years, rapid progress has been made in noninvasive imaging of coronary artery disease that provides information on plaque composition. Currently available imaging techniques will be reviewed. One of the most promising techniques, multidetector-row computed tomography (MDCT) of the coronary arteries, will be described in detail, including strategies for improving image quality by managing heart rate.

Figure 1. Atherosclerotic lesions that obstruct blood flow to the same extent may differ in their likelihood of causing a cardiovascular event. The plaque on the right, which has a necrotic core, is more likely to rupture than the fibrous plaque on the left.[2]



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CURRENT IMAGING TECHNIQUES

Invasive Techniques

Angiography

Currently, the reference standard for diagnosing coronary artery disease is selective cardiac catheterization with angiography using iodinated contrast media (CM), which provides high spatial resolution of the vessel lumen. However, this procedure requires arterial access. While arterial penetration allows percutaneous intervention to be performed immediately if necessary, it is also associated with a small risk of adverse events including bleeding, hematoma, infection, stroke, coronary artery dissection, and death.[3,4] Moreover, angiography effectively demonstrates thrombotic occlusion or vessel stenosis, but does not elucidate the size or composition of atherosclerotic plaques. If a plaque is not obstructive—as many plaques prone to rupture are not—it may not be detected. Indeed, it is estimated that nearly two thirds of all myocardial infarction (MI) originate with atherosclerotic lesions that do not obstruct blood flow prior to rupture.[5] Thus, it is reasonable that 20% to 40% of patients considered at risk for cardiovascular disease have normal angiograms.[1,6]

Intravascular Ultrasound

Intravascular ultrasound (IVUS) is a catheter-based technique that not only identifies areas of stenosis, but also determines plaque composition (ie, calcification, thrombus, the dimensions of the fibrous cap, and lipid content). A recent study showed that IVUS detected significant lesions in patients with minimal angiographic findings, and that these lesions predicted the likelihood of cardiac events.[7] However, the adverse events associated with arterial access for angiography are also a concern with this technique, which is also time-consuming and requires technical skills. Furthermore, the catheter cannot penetrate beyond areas of severe stenosis.

Noninvasive Imaging Techniques

Theoretical advantages of noninvasive imaging of the cardiovascular system include increased safety because no arterial access is needed, rapid acquisition of data, detection of nonstenotic coronary lesions, and lower cost (in part because less physician and hospital time are required).[3,8] With improvements in technology, noninvasive methods may eventually be used to routinely assess asymptomatic or minimally symptomatic atherosclerosis and monitor disease progression, stabilization, or regression.[9]

Imaging of the coronary artery system presents special challenges because of the small diameter of the coronary vessels and the complex 3-dimensional (3D) shape and rapid movement of these vessels during the cardiac cycle.[10] Achieving adequate image quality has been a major goal of research and development in this field.

Magnetic Resonance Imaging

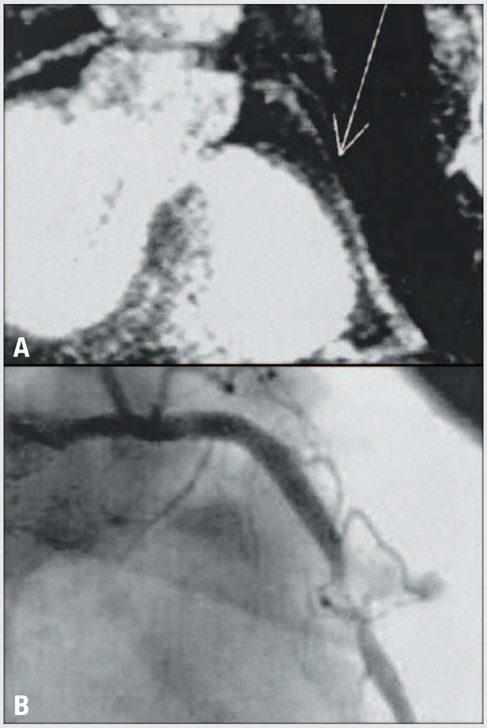
Magnetic resonance imaging (MRI) provides excellent soft tissue resolution and is able to image plaque in the peripheral vasculature, aorta, and carotid arteries.[3, 10, 11] When human coronary arteries in autopsy samples were examined, MRI was able to identify fatty, fibrous, and calcified plaque components.[12] However, difficulties have been encountered in imaging coronary arteries in vivo because of a combination of cardiac and respiratory motion artifacts, and the nonlinear movement, small size, and location of the arteries.[10] Although research is ongoing, visualization of the lumen of a coronary artery can be difficult because of limitations in the spatial and temporal resolution of MRI **(Figure 2)**.[3]

Computed Tomography

One of the most promising noninvasive procedures is computed tomographic (CT) angiography. Unlike traditional x-ray imaging that produces a 2D snapshot, CT angiography involves taking thin x-ray scans of <1-mm thickness from multiple directions. The multiple scans are combined using special computer algorithms to form an image of a "slice" of the body. Adjacent slices are then stacked by computer to produce a 3D image. CT is successfully used for 3D imaging of the chest, abdomen, kidney, liver, brain, and heart.[13] When used to diagnose the source of chest pain, the possibilities of heart attack, pulmonary embolism, and aortic dissection can be assessed simultaneously.[14]

To eliminate motion artifacts from cardiac CT scans, the procedure must be synchronized with the heart cycle. Two primary techniques are used to synchronize CT scanning with the patient's electrocardiogram (ECG): prospective triggering and retrospective gating. Prospective triggering directs the CT scanner to take x-ray scans only at a certain phase of the cardiac cycle.

Figure 2. Imaging of an obstructed right coronary artery with magnetic resonance imaging (A) and an angiogram (B).[3]



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It is usually the diastolic phase because this is when the heart has the least motion. Prospective triggering has the advantage of minimizing x-ray exposure because only the minimum data needed is acquired. However, it depends on a regular heart rate because an arrhythmic heart may confuse the ECG trigger. Also, because the motion pattern of the major cardiac arteries differ during the cardiac cycle, prospective triggering may produce images optimized for only some of the arteries.[15]

In retrospective gating, the heart is scanned continuously for several cycles, but only scans from a particular phase of the ECG are used for image reconstruction. This improves visualization of the heart, but exposes the patient to a higher dose of x-ray radiation.[15] Retrospective gating is currently used for CT angiography of the heart.

Electron Beam Computed Tomography

Electron beam CT (EBCT) scanners were the first generation of CT scanners used for cardiac studies. The EBCT imaging process involves production of a continuous 30-degree x-ray fan beam that passes through the patient and is collected by the stationary row of detectors. Data acquisition is prospectively triggered based on ECG data, and image slices are acquired sequentially as the patient table is incrementally advanced.

Advantages of EBCT are the low radiation exposure given to the patient and the single image acquisition time of only 50 to100 milliseconds, which limits motion artifacts.[9] The disadvantages of EBCT are its somewhat low signal-to-noise ratio, its relatively long total scan time, and images limited to one point of the cardiac cycle.[9]

Images produced by EBCT for clinical use are generally obtained without intravascular contrast and are used to quantitate total calcium in the coronary tree. The relevance of this measurement is controversial, as plaques likely to rupture may not be calcified.[16]

According to a consensus report from the American College of Cardiology/American Heart Association, a negative EBCT makes the presence of atherosclerotic plaque, including unstable plaque, unlikely.[16] However, a positive EBCT confirms the presence of coronary atherosclerosis and is consistent with the possibility of occlusive heart disease,[16] which may lead to coronary events.

Multidetector-Row Computed Tomography

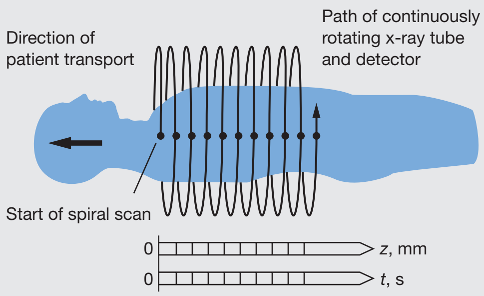
Multidetector-row computed tomography (MDCT) gathers multiple images simultaneously and continuously, thus acquiring a greater amount of diagnostic information.[3] In this method a gantry, which houses the x-ray source, collimators to focus the beam, and detectors, is rotated around the patient. The data are retrospectively ECG-gated during analysis.

In the pre-spiral CT era, one 360-degree rotation of the gantry produced data for one image slice of the patient. To capture the next slice, the patient table was moved a distance equal to the slice thickness and came to a complete stop. The gantry then made another 360-degree rotation in the opposite direction, the table was moved again, and so on. The computed slices were “stacked” in a computer and a 3D image was constructed. Substantial cardiac motion artifacts were introduced because the acquisition time for each image was 1 to 2 seconds and the utility of CT in cardiac imaging was limited.

The introduction of slip-ring technology in the late 1980s allowed the gantry to rotate continuously in one direction. This allowed scanning by rotating the gantry for multiple revolutions without stopping while the patient table slowly advanced to produce a so-called spiral CT **(Figure 3)**.[17] Total scan time was significantly reduced.

In the late 1990s, spiral CT scanners were further improved with the addition of multiple detector rows and increased rotation speed of the gantry. MDCT

Figure 3. The scanning principle of single spiral computed tomography (CT). In a multiple spiral CT, such as a 4-detector–row CT, the helix in the schematic would be a quadruple helix that covers 4 times the distance in one turn.[17]



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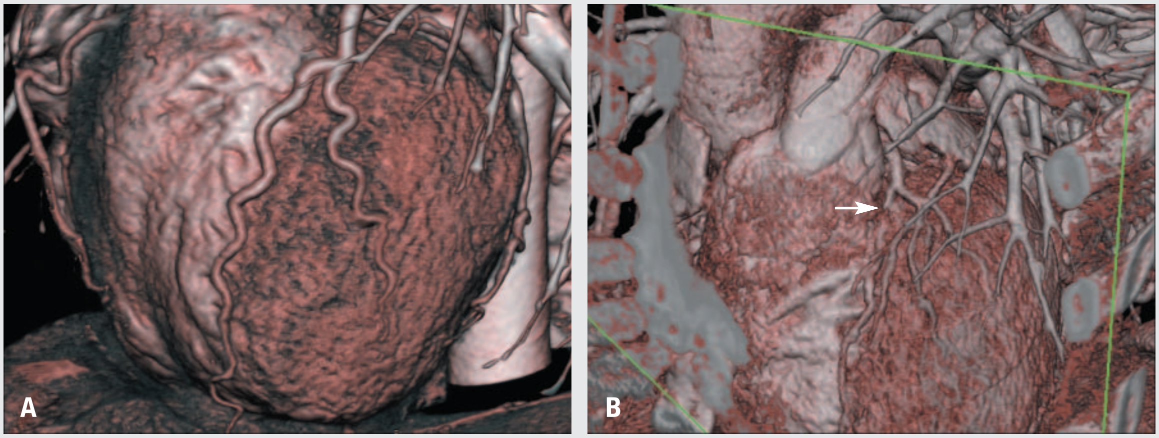
allows some overlap between the rotations, which significantly improves spatial resolution. Compared to single-detector–row CT, the 16-detector–row CT acquires 16 slices per rotation instead of 1. Although 16-, 32-, and 40-detector–row CT systems are available, the state of the art is currently a 64-detector–row CT, which acquires 64 slices simultaneously, scanning the heart within 5 seconds (ie, 5 heart beats).[18]

Improvements in CT with respect to scanning speed and resolution over the past few decades are summarized in **Table 1**.[13] An example of a high-resolution MDCT scan of the coronary vessels is shown in **Figure 4**.

THE CLINICAL UTILITY OF MDCT

While MDCT to examine the coronary arteries is still investigational, it is hoped that MDCT will eventually be used instead of angiography for routine assessment of the coronary arteries. The procedure can be performed more quickly than angiography—the measurement is made within a few heartbeats—and requires less skill to perform than cardiac catheterization. Risk of bleeding is also significantly reduced, and no hospitalization is required. Although uses of MDCT are still being explored, the greatest benefits may be rapid assessment of chest pain (differentiating heart attack, pulmonary embolism, and aortic dissection in a single procedure) and noninvasive assessment of progression of coronary artery disease **(Table 2)**. Not only can the location and extent of stenoses be followed over time, but the composition of plaques (ie, fibrous versus lipid-rich)

Figure 4. Images of the coronary arteries obtained with 64-detector–row computed tomography. Image A is a scan of a normal heart. Image B shows a stenosed coronary artery (arrow).



Provided by Dr Fishman.

Table 1. The Evolution of Computed Tomography[13]

Year	Scan Speed (sec)	Scan Thickness (mm)	Interscan Spacing (mm)	Total No. of Slices
1980	10	10	10	25-30
1985	5	8-10	8-10	30-45
1990	1	3-5	3-5	100
1995	0.75	3	2-3	100
1999	0.5*	1-3	1-3	220
2003	0.4*	0.5-0.75	0.5-0.75	400-1200
2004	0.33*	0.5-0.6	0.5-0.75	600-2500

*Scanner rotation speed.

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Table 2. MDCT Angiography: Potential Clinical Uses of This Noninvasive Technology

Diagnosis of chest pain by simultaneous assessment of

- Coronary arteries for stenosis or thrombosis
- The aorta for dissections or aneurysms
- The pulmonary vasculature for embolism

Global assessment of coronary artery disease

- Plaque location, size, and composition
- Changes in plaque characteristics over time with or without treatment

Presurgical or interventional planning

can be assessed. As physicians become more familiar with the technology, it is likely that other applications will be found.

A number of clinical studies have compared 16-detector–row CT with conventional coronary angiography[19] or with intravascular ultrasound.[9, 20] Because the introduction of 64-detector–row CT is recent, published studies comparing the results with other imaging modalities are not yet available. However, comparisons of 16-detector–row CT with angiography have given positive results.[21-23] In 30 patients with an angiographically proven absence of significant coronary artery stenoses, it was possible to visualize 93% of the overall length of the coronary arteries without motion artifacts. Furthermore, vessel diameters measured by MDCT closely correlated with those given by quantitative coronary angiography.[21] In another study of 59 patients with suspected coronary obstructions, 58 had analyzable data sets with a sensitivity and specificity for defining luminal obstructive disease of 95% and 86%, respectively. No patients with significant obstructions were incorrectly diagnosed.[22] Similar results were obtained in a study of 77 patients with suspected CAD. In 57 of these patients, all coronary arteries were evaluable, and stenoses of >50% were correctly identified with accuracy similar to that of angiography (sensitivity: 92%; specificity: 93%). In a subgroup of 36 patients with a heart rate <60 bpm, 96% of all coronary arteries were evaluable.[23]

MDCT also differentiates plaques based on their content of calcified, lipid, or fibrous material. Detection of calcified plaques by 16-detector–row CT has been shown to be nearly identical to that of EBCT (98.7% sensitivity and 100% specificity).[8] MDCT results have also been directly compared with IVUS results. A study of 14 patients with cardiovascular disease affecting 46 vessel segments showed that 16-detector–row CT identified 37 of these segments (80.4%). Unidentified segments were located distally.[24] In analyzable segments, the presence of plaque, the symmetry of plaque distribution, plaque calcification, and vessel remodeling could be identified.[24] In a study of 22 patients without significant coronary stenoses, 16-detector–row CT had a sensitivity of 82% and a specificity of 88% for detection of any plaque compared with IVUS. The overall sensitivity was maximal for calcified plaque (94%), lower for plaques with some calcification (78%), and lowest for plaques without calcification (53%).

Detection was most accurate for large plaques in proximal segments.[20] However, the use of CM may not have been optimized in this study, with the result that the signal density of the contrast in the lumen was similar to that of the noncalcified plaques, which made the plaques difficult to detect.[20] Furthermore, the resolution of current 64-detector–row CT is in the range of 0.3 to 0.4 mm.

MDCT has been used to differentiate the unstable plaques associated with acute MI from the stable plaques associated with stable angina pectoris. Noncalcified plaques are more often found in patients with MI than in patients with stable angina pectoris, and calcified plaques are more often found in patients with stable angina pectoris than in patients with MI **(Figure 5)**.[25] MDCT also can detect thrombus associated with MI.[26]

OPTIMIZING MDCT RESULTS

Strategies to optimize MDCT imaging of the coronary arteries include improved instrumentation to obtain rapid scans with high spatial resolution (**Table 1**),[13] careful choice of the reconstruction time point in the cardiac cycle, control of heart rate to minimize movement artifacts, and optimum contrast enhancement.[15, 27] The latter 2 strategies may be managed by the physician directing the examination.

Managing Heart Rate

Heart rate is an important parameter for achieving optimal imaging in MDCT. In a survey of the problems experienced while imaging 110 patients with a 4-detector–row CT scanner, the most common problem was blurring of the image by cardiac motion.[27] In general, when the heart rate is <65 bpm, the image can be reconstructed from a single heart cycle. When heart rate is >65 bpm, most MDCT image reconstruction algorithms use data from 2 consecutive heart cycles **(Figure 6)**.[28] However, 2 absolutely equal heart cycles are necessary to generate an image free of

Figure 5. Comparison of plaque composition determined by multidetector-row computed tomography in patients with acute myocardial infarction (AMI) or stable angina pectoris (SAP). Data for plaques of mixed composition do not differ between groups and are not shown.[25]

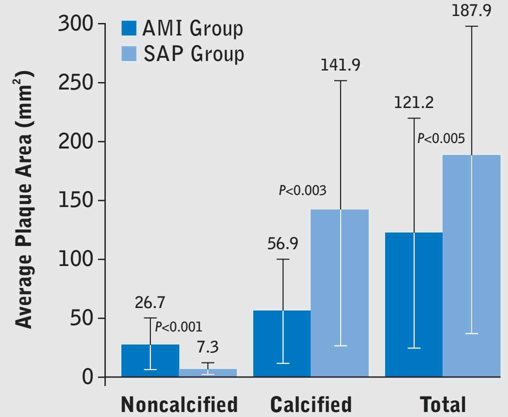

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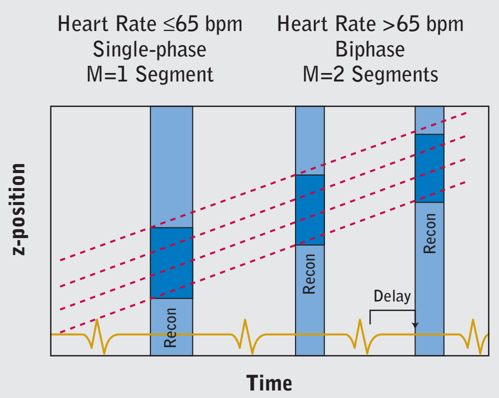
Figure 6. A computed tomography image reconstructed from 2 segments may have lower resolution due to nonidentical positioning.[28]



Single-phase reconstruction with a temporal resolution of 250 ms ($T_{rotation}$/2=250 ms) (left).

Reconstruction with M=1 sectors is performed for heart rates ≤65 bpm.

Biphase reconstruction with a temporal resolution of up to 125 ms ($T_{rotation}$/4=125 ms) using obtained image data of 2 consecutive RR-intervals (right).

Reconstruction with M=2 sectors is performed for heart rates >65 bpm.

Recon=image reconstruction at a defined time point within the RR interval; z-position=patient position.

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motion artifacts, a condition that is not always found. Another complication is the need for the patients to hold their breath during scanning because this inevitably increases heart rate during the procedure.[29] A slow, regular heart rate is ideal for image quality.

The impact of heart rate on image quality was first established during studies using 4-detector–row CT. When 94 patients undergoing 4-detector–row CT were grouped according to vessel segment visibility, patients with the highest number of analyzable segments had the lowest heart rate (mean 60±10.1), and segment visibility was inversely correlated with heart rate (r=0.48, *P*<0.0001).[28] Gerber and colleagues analyzed coronary segments from 126 patients with a 4-detector–row CT scanner and observed motion artifacts in only 13% of coronary segments at heart rates of 51 to 60 bpm.[30] However, artifacts were observed in 71% of coronary segments at heart rates of 61 to 70 bpm.[30] Overall sensitivity for stenosis detection with 4-detector–row CT decreased from 62% to 33% when the heart rate increased from ≤70 bpm to >70 bpm **(Figure 7)**.[31]

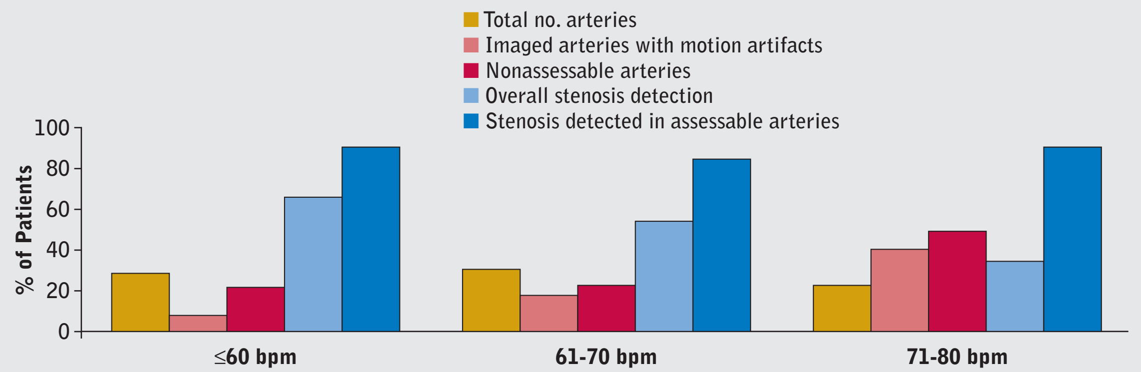
To assess the effect of heart rate on the consistency of 4-detector–row CT in quantifying coronary artery calcium, Hong and colleagues acquired 2 consecutive MDCT data sets on patients with various heart rates and found that variability between the 2 scans in the measurement of calcium score, volume, and mass increased with increasing heart rate.[32] Thus, lower heart rates are associated with both better image quality and better reproducibility.

Because the advantages of a slower heart rate were convincingly established with 4-detector–row CT, this topic was less thoroughly examined with 16-detector–row CT. However, a study verified that the percentage of visualized vessel length was significantly higher in patients with a heart rate ≤60 bpm (96%) compared with patients with a heart rate >60 bpm (89%).[21] In other studies, patients with heart rates >60 or 65 bpm were premedicated to slow the heart rate.[22, 23]

Use of β-Blockers

β-Adrenergic receptor blocking agents (β-blockers) are recommended to reduce heart rate.[27] Because patients referred for radiology examinations often have persistent coronary disease requiring the use of β-blockers, in many cases optimal imaging may be obtained with no change in medication. In several studies, >60% of patients referred for conventional selective coronary angiography were taking long-term β-blockers, indicating that the majority of patients have an appropriately controlled heart rate.[22, 23, 28] For

Figure 7. Motion artifacts are increasingly important at higher heart rates in 4-row multidetector computed tomography.[31]



patients not taking β-blockers, short-acting β-blockers are increasingly used to control heart rate and improve image acquisition.[33] However, β-blockers may slightly increase the risk of bronchospasm during the procedure.[34] With the new 64-slice MDCT scanners, optimal studies may be performed at higher heart rates.

Choice of Contrast Media

The CM chosen for MDCT may increase the heart rate, thereby reducing image quality. There are differences between the types of CM available for use, which historically have evolved from a high-osmolar, ionic composition to a low-osmolar, ionic or nonionic composition, and finally to an isosmolar, nonionic composition. Over time, the osmolarity of CM has steadily decreased with minimal effects on iodine content **(Figure 8)**.[35] The osmolarity of a CM (the number of particles in a given volume) affects fluid movement in the body because fluid moves to areas of high particle concentration. Thus, fluid moves out of tissues and cells when high osmolar CM is in a blood vessel, causing local dehydration. Iodixanol, the only isosmolar CM currently available, is isosmolar with blood.

Numerous studies have found that more frequent changes in heart rate and blood pressure result from the use of a high-osmolar CM (HOCM) than from the use of a low-osmolar (LOCM), particularly in patients with severe heart disease.[36] Furthermore, in a double-blind, prospective study of 110 patients, ioxaglate, an ionic dimeric LOCM, increased heart rate to a greater extent than iodixanol, a nonionic, dimeric isosmolar CM (IOCM).[37] This result was confirmed by a study of 102 patients given iodixanol and ioxaglate **(Figure 9)**.[38] Thus, the use of IOCM during MDCT may improve image quality by not increasing heart rate.

Observed changes in heart rate may be an indirect result of CM-induced lowering of blood pressure,[39, 40] which is more likely to occur in patients with severe coronary stenoses or myocardial insufficiency. In a crossover study of 48 patients with compromised left ventricular function, cardiac catheterization was performed with iodixanol (an IOCM) or iohexol (a LOCM), and the effect on left ventricular end-diastolic pressure (LVEDP) was measured.[40] While a nonsignificant decrease in LVEDP was observed with both agents immediately after injection, at 60 to 180 seconds after injection, LVEDP was significantly higher with iohexol (P=0.0012).[40] Because iodixanol resulted in a lower and shorter rise in LVEDP, iodixanol may be the safer alternative in catheterization procedures for high-risk patients.

Figure 8. Osmolality of contrast media relative to plasma.[35]

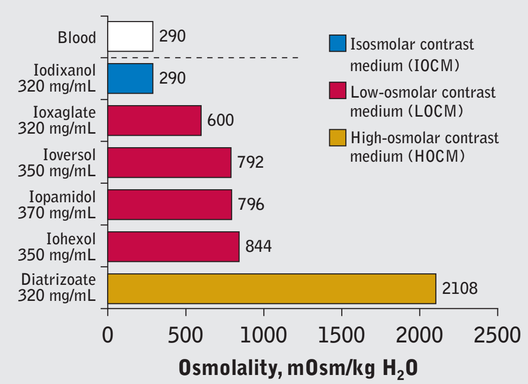


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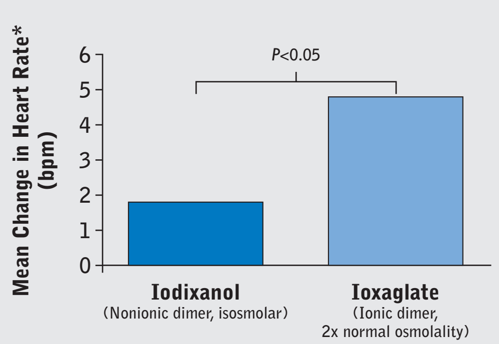
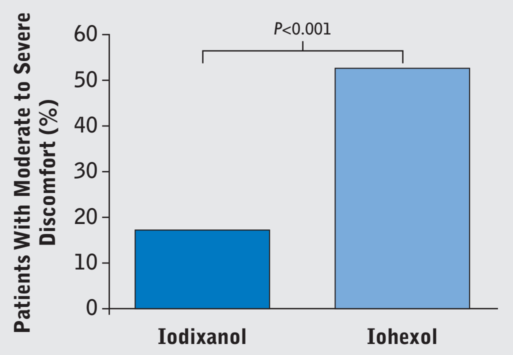
Figure 9. Increases in heart rate depend on the contrast medium used.[38]



*Before to after contrast injection.

Figure 10. The incidence of moderate to severe discomfort (warmth or pain) upon injection of isosmolar contrast medium versus low-osmolar contrast medium during coronary angiography.[39]



Heart rate also may be influenced by patient discomfort and stress that in turn are affected by the choice of CM. Patients may report sensations of warmth or pain as CM is injected, depending on its composition. This pain is likely due to fluid movement from cells and tissues into the circulatory system when CM with an increased osmolarity is present. Injection-related pain and heat sensations are less frequent with the IOCM iodixanol during cardiac angiography procedures than with the LOCM iohexol **(Figure 10)**, which has been confirmed in a number of comparative clinical studies.[37-39, 41]

The choice of CM also may affect the incidence of adverse coronary events in high-risk cardiac patients. The COURT trial (<u>CO</u>ntrast media <u>U</u>tilization in high-<u>R</u>isk P<u>T</u>CA [Percutaneous Transluminal Coronary Angioplasty]), performed in high-risk patients undergoing coronary artery intervention with iodixanol or ioxaglate, examined in-hospital major adverse clinical events.[42] This study revealed a 45% reduction in major adverse clinical events in the iodixanol cohort. More recently, the results of the VICC (<u>V</u>isipaque vs <u>I</u>sovue in <u>C</u>ardiac <u>C</u>atheterization) trial demonstrated a significant reduction in the number of periprocedural myocardial events with iodixanol compared to iopamidol.[43]

Optimizing Administration of CM

Use of iodinated CM during MDCT is essential for visualization of the lumens of the coronary arteries. With respect to imaging efficacy, various types of CM, including iodixanol and iopromide, have given satisfactory results with 16-detector–row CT.[21, 22, 24]

The method used to inject CM influences image quality. For example, the duration of the injection affects the degree of contrast enhancement and optimal scan timing. A fast injection of contrast followed by a slow injection can prolong contrast enhancement at the imaging site.[44] For newer, faster scanners, optimal contrast enhancement is required for a shorter period of time, and a lower volume of CM can be used. For example, CT angiography with a 4-row scanner requires ~120 mL of CM, whereas the same procedure with a 16-row scanner requires only 100 mL of CM.[26] A 64-detector–row CT scan can be completed with 80 mL of CM.[45] Thus, optimized high-speed MDCT may require less CM than angiography.

Injection of saline immediately after contrast injection may improve image contrast by increasing the amount of CM available for image acquisition and pushing the contrast bolus forward.[44] An automatic dual-head power injector is required for administration of both CM and a saline flush.

The concentration of CM used may influence image quality. If the CM present in the lumen is too dense, it may be difficult to see plaque in the vessel wall. A study demonstrated that high contrast concentration administered at high flow rates obscured detection of coronary calcifications.[46] A somewhat lower contrast attenuation may be required to differentiate the different types of plaque present in the artery wall.[20]

As MDCT scanners with better resolution are introduced into the clinic, the details of administering CM will be optimized and customized for each patient.

CONCLUSIONS

Cardiovascular imaging has tremendous potential for identifying patients with atherosclerotic disease likely to result in adverse cardiac events. MDCT is a non-invasive alternative to coronary angiography with high temporal and spatial resolution, particularly in newer scanners. Instead of inserting a coronary catheter for selective dye infusion as in angiography, iodinated CM is infused intravenously through an antecubital vein. Using CT scanners with 16 or more rows of detectors, image data can be collected rapidly with good spatial resolution. With ECG-based algorithms, a specific time point at which most segments of the coronary arteries are observable can be chosen for optimal visualization. Results are comparable to those obtained with angiography, though additional data on plaque composition also can be obtained with MDCT, which may identify patients with vulnerable plaques who are at risk for coronary events.

Optimization of heart rate is important to obtain high-quality results with MDCT. Heart rates >60 bpm can increase motion artifacts. Heart rate can be controlled with the use of β-blockers and by using the appropriate CM. An IOCM is less likely to affect cardiac function and stimulate the heart rate directly and is less likely to increase heart rate indirectly by increasing patient discomfort. Overall, an IOCM may result in a better imaging outcome than a LOCM due to slower heart rate, less patient motion due to discomfort, and fewer major adverse events.

With proper use of recently developed scanners, β-blockers, and CM, MDCT can noninvasively and accurately provide important diagnostic information on the condition of the heart and its vessels. These findings should support appropriate treatment decisions to reduce the morbidity and mortality resulting from cardiac disease.

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INSTRUCTIONS FOR RECEIVING CME CREDIT

The following examination provides the opportunity to assess your knowledge and understanding of the material presented in this monograph.

To obtain 1.5 hours of Category 1 CME credit, you must:

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POSTTEST

Multidetector-Row Computed Tomography to Detect Coronary Artery Disease: The Importance of Heart Rate

1. Select the adverse event that may be associated with an invasive diagnostic technique (angiography or IVUS).

A. Bleeding
B. Hematoma
C. Infection
D. All of the above

2. Limitations of traditional angiography include:

A. Failure to detect stenosis
B. Poor image quality
C. Failure to identify plaques as stable or unstable
D. All of the above

3. Select the ECG synchronization technique for CT that generally gives the lowest x-ray exposure.

A. CT does not expose patients to x-rays
B. Prospective triggering
C. Retrospective gating
D. Both prospective triggering and retrospective gating

4. Choose the true statement:

A. EBCT or MDCT imaging can be used to measure calcium in the coronary tree, which indicates the presence of atherosclerosis.
B. High-quality noninvasive imaging of the coronary arteries was achieved with the earliest CT instrumentation.
C. Magnetic resonance imaging is unable to differentiate between fibrous and fatty plaques under ideal conditions.
D. All of the above.

5. Having multiple detector rows instead of a single detector row during CT allows for:

A. Increased resolution
B. Decreased scan time
C. Fewer motion artifacts
D. All of the above

6. Select the condition associated with chest pain that can be diagnosed by MDCT:

A. Pulmonary embolism
B. Thrombus in a coronary artery (MI)
C. Aortic dissection
D. All of the above

7. Compared to patients with stable angina, patients with acute coronary syndromes have:

A. More calcified plaques
B. More noncalcified plaques
C. More total plaques
D. All of the above

8. Potential strategies to maintain a regular slow heartrate to improve MDCT image quality include:

A. Short breath-hold times
B. Use of β-blockers
C. Use of isosmolar CM
D. All of the above

9. Choose the property that is not affected by contrast medium.

A. Image quality
B. Pain or warmth at the injection site
C. Thickness of the vessel wall
D. Heart rate

10. Choose the answer that completes the following sentence: In the past 20 years, our ability to accurately perform noninvasive imaging with MDCT has:

A. Improved dramatically
B. Improved slightly
C. Not improved
D. Regressed

ANSWER SHEET

1. A B C D	3. A B C D	5. A B C D	7. A B C D	9. A B C D
2. A B C D	4. A B C D	6. A B C D	8. A B C D	10. A B C D

PROGRAM EVALUATION

Multidetector-Row Computed Tomography to Detect Coronary Artery Disease: The Importance of Heart Rate

Please evaluate this CME monograph using the following scale:

1 = poor 2 = fair 3 = average 4 = good 5 = excellent

1. **How successfully did this program meet its stated learning objectives?**

   – Discuss the potential advantages of noninvasive imaging of coronary arteries.

   1 2 3 4 5

   – Summarize recent technological advances in MDCT angiography.

   1 2 3 4 5

   – Describe solutions for reducing heart motion-caused image artifacts in MDCT angiography.

   1 2 3 4 5

   – Review the importance of contrast media in optimizing the quality of MDCT images.

   1 2 3 4 5

2. **How would you rate the clinical usefulness of this program?**

   1 2 3 4 5

3. **How well did this learning format work with your learning style?**

   1 2 3 4 5

4. **Overall, how satisfied were you with this activity?**

   1 2 3 4 5

5. **Accredited CME programs must be "free from commercial bias for or against any product." In this regard, how would you rate this program?**

   1 2 3 4 5

6. **Do you expect to make any changes in your practice or attitudes as a result of this activity?**

   ☐ Yes ☐ No

   If yes, please explain

   ____
   ____
   ____
   ____
   ____

7. **Suggestions for future programs:**

   ____
   ____
   ____
   ____
   ____

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☐ I would prefer not to receive correspondence from CBC.

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