



Current Applications of Coronary and Cardiac Multidetector Computed Tomography

James K. Min, MD,¹ Fay Lin, MD,¹ Samuel Wann, MD^{2*}

¹ Weill Cornell Medical College, New York Presbyterian Hospital, New York, NY, USA.

² Wisconsin Heart Hospital, Milwaukee, WI, USA.

Abstract

Cardiovascular disease remains the principal cause of death in the modernized world. Several novel noninvasive imaging techniques have been recently developed to improve diagnosis of cardiac and coronary disease. Of these advances, multidetector computed tomographic (MDCT) angiography has evolved most dramatically to transform computed tomography from a single-slice trans-axial modality to a three-dimensional volumetric technique. Current generation 64-detector row CT scanners allow for large volume coverage with submillimeter spatial and sub-second temporal resolution. These advances enable important new applications for MDCT in the assessment of cardiac and coronary anatomy. In this report, we discuss in depth potential appropriate uses of cardiac and coronary MDCT angiography.

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Cardiovascular disease (CVD) is the principal cause of morbidity and mortality in the modernized world, accounting for the deaths of more than 16 million individuals per year. Epidemiologic studies suggest that CVD is occurring at earlier ages and at higher costs, somewhat paradoxically related to improved economic conditions worldwide, and associated changes in diet and physical activity. We are facing an epidemic of obesity and metabolic syndrome and an increasing incidence of CVD. These disquieting data necessitate improved and earlier detection and better characterization of CVD. Numerous non-invasive imaging modalities have been extensively studied for the diagnosis

of CVD and for directing patient-specific therapies. These techniques include magnetic resonance imaging, single photon emission computed tomography, echocardiography and multidetector computed tomography.¹⁻⁶

Recently, advances in computed tomography (CT) technology have permitted the emergence of the use of current generation 64-detector CT scanners as an imaging modality with the ability to comprehensively evaluate both coronary and cardiac structure and function.⁷⁻⁹ At its introduction in the early 1970s, CT technology possessed certain limitations (including limited spatial and temporal resolution) that precluded its use for cardiac imaging. The

*Corresponding Author: Samuel Wann, Chairman, Department of Cardiovascular Medicine, Wisconsin Heart Hospital, 10000 Bluemound Road, Milwaukee, Wisconsin 53226 USA. Tel: +1-414-266-9700. E-mail: samuelwann@whvc.org.

small diameter of the coronary arteries requires high spatial resolution, while perpetual coronary artery motion demands high temporal resolution. It was not until the late 1990s when CT achieved submillimeter spatial resolution, therapy permitting the acquisition of data of an isotropic nature, namely that each voxel (or data element) is of equal resolution in the x-, y- and z-planes. Furthermore, at this time, CT achieved sub-second temporal resolution, thereby permitting acquisition of virtually motion artifact-free data. Today, with the recent introduction of 64-slice MDCT scanners, rapid volume coverage can now be achieved which, when coupled with high spatial and temporal resolution, results in exquisite cardiac and coronary artery imaging.

The purpose of this report is to review appropriate potential uses for cardiac and coronary MDCT imaging. The potential uses are primarily based on the recently released ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR Appropriateness Criteria for Cardiac

Computed Tomography and Cardiac Magnetic Resonance Imaging.¹⁰ In case where the authors' opinion of the clinical utility of cardiac MDCT imaging diverges from the appropriateness criteria set forth, it will be noted.

Perhaps the greatest optimism for the successful integration of cardiac MDCT into daily clinical practice lies rooted in the detection of symptomatic coronary artery disease. Within this indication, numerous subsets of patients can be delineated (Table 1).

Although there is great hope for MDCT to be able to successfully diagnose and stratify risk in symptomatic patients presenting with chest pain, there is in fact little data to support its incremental clinical value above and beyond more traditional non-invasive imaging modalities. Nonetheless, preliminary positive studies examining the role of MDCT in the evaluation of chest pain in patients without known coronary artery disease are beginning to emerge.

In a study evaluating 31 symptomatic emergency department patients with chest pain for ≥ 30 minutes, non-diagnostic electrocardiograms and normal cardiac enzyme levels, MDCT coronary angiography (utilizing 4- and 16-slice CT scanners) was able to detect significant disease in 21 individuals who were ultimately diagnosed with an acute coronary syndrome. The sensitivity and specificity were 95.5%, and 88.9%, respectively.¹¹ This early study, utilizing primarily older generation scanners with inferior temporal and spatial resolution, lent initial credence to the value of MDCT in the evaluation of symptomatic patients. It may be reasonable to assume that with the introduction and more widespread use of newer, improved 64-detector scanners, the results of this study may be expanded to larger populations.

In a similar study, 69 individuals who presented to the emergency department with chest pain were evaluated with 16-slice chest MDCT angiography to determine whether MDCT might provide incremental value in the assessment of chest pain.¹²

Table 1. Appropriateness Criteria for Coronary CTA

Detection of CAD: Symptomatic—Evaluation of Chest Pain Syndrome (Use of CT Angiogram)

- Intermediate pre-test probability of CAD
- ECG uninterpretable OR unable to exercise

Detection of CAD: Symptomatic—Evaluation of Intra-Cardiac Structures (Use of CT Angiogram)

- Evaluation of suspected coronary anomalies

Detection of CAD: Symptomatic—Acute Chest Pain (Use of CT Angiogram)

- Intermediate pre-test probability of CAD
- No ECG changes and serial enzymes negative

Detection of CAD with Prior Test Results—Evaluation of Chest Pain Syndrome (Use of CT Angiogram)

- Uninterpretable or equivocal stress test (exercise, perfusion, or stress echo)

Structure and Function—Morphology (Use of CT Angiogram)

- 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

Structure and Function—Evaluation of Intra- and Extra-Cardiac Structures (Use of Cardiac CT)

- Evaluation of cardiac mass (suspected tumor or thrombus)
- Patients with technically limited images from echocardiogram, MRI, or TEE
- Evaluation of pericardial conditions (pericardial mass, constrictive pericarditis, or complications of cardiac surgery)
- Patients with technically limited images from echocardiogram, MRI, or TEE
- Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation
- Noninvasive coronary vein mapping prior to placement of biventricular pacemaker
- Noninvasive coronary arterial mapping, including internal mammary artery prior to repeat cardiac surgical revascularization

Structure and Function—Evaluation of Aortic and Pulmonary Disease (Use of CT Angiogram*)

- Evaluation of suspected aortic dissection or thoracic aortic aneurysm
- Evaluation of suspected pulmonary embolism

*Non-gated, CT angiogram which has a sufficiently large field of view for these specific indications

At a one month follow-up, the summation of clinical history, physical examination, any subsequent cardiac



workup and MDCT were evaluated. Of the 69 individuals who presented, 13 individuals (19%) were diagnosed with significant MDCT findings above and beyond “standard” workup. Ten of thirteen of these findings were cardiac, while 3 were non-cardiac. The three non-cardiac significant findings included pericarditis with pericardial effusion, pneumonia, and pulmonary embolism. The inclusive sensitivity and specificity for all causes of chest pain (cardiac and non-cardiac) were 87% and 96%, respectively.

While there is not an abundance of data examining the role of MDCT coronary angiography for the evaluation of symptomatic chest pain, there is nevertheless a large body of data that demonstrates that high-row (16- and 64-slice) MDCT angiography is highly accurate in the detection of obstructive coronary artery lesions (Figure 1 and 2).

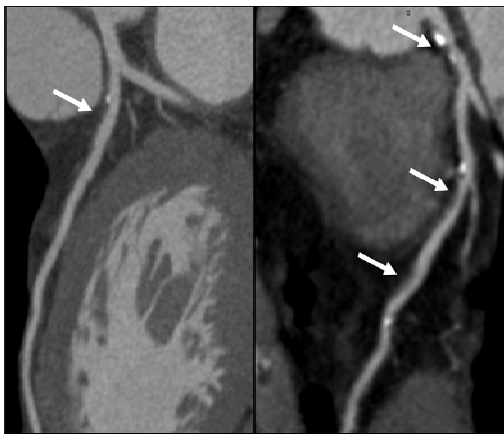


Figure 1. CTA (curved reformatted image) of left anterior descending coronary artery. Arrows indicate regions of mild, non-obstructive atherosclerotic plaque with no significant stenosis

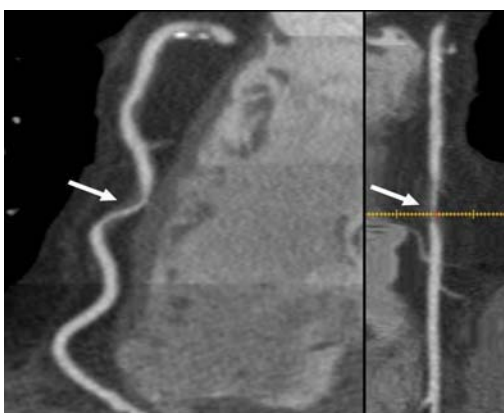


Figure 2. CTA of left anterior descending coronary artery. Arrows indicate regions of significant, obstructive atherosclerotic plaque

The earliest demonstration of reliable non-invasive coronary angiography with 16-slice MDCT was published by Nieman and colleagues in 2002.¹³ They studied 59 primarily male patients in whom obstructive coronary artery disease

was suspected for whom cardiac catheterization had been planned. Prior to conventional coronary angiography, these patients underwent MDCT coronary angiography. MDCT scans were compared to quantitative coronary angiography (QCA). In this study, only 231 of 332 coronary segments (69%) could be properly evaluated by MDCT. In evaluable segments, detection of an obstructive stenosis (defined as >50% by QCA) exhibited a sensitivity, specificity and negative predictive value of 95%, 86% and 97%, respectively. This study was noteworthy for numerous reasons. First, this study demonstrated feasibility of non-invasive coronary angiography with MDCT. Moreover, the study underscored several important factors that affect overall accuracy of MDCT angiography. Twenty arteries were incorrectly assigned by MDCT as stenotic, each exhibiting significant vessel calcification. This limitation has been repeated time and again in MDCT angiography studies, and highlights the importance of the partial volume averaging effect of calcific plaque in the over-estimation of coronary artery stenosis.

In a similar study employing 16-slice MDCT coronary angiography, Ropers et al. found 38 of 308 vessel segments to be unevaluable and thus excluded these segments from final analysis.¹⁴ The design of their study consisted of a per-vessel analysis rather than a per-segment analysis. This issue is central to the accuracy of MDCT angiography because, as the authors correctly noted, a high-grade proximal stenosis may likely affect downstream image in the distal affected vessel. Employing this strategy, the sensitivity and specificity for the detection of obstructive stenosis (defined as >50%) was 92% and 93%, respectively.

The accuracy of MDCT coronary angiography has also been examined in a population with a high prevalence of coronary artery disease.¹⁵ In a study of 60 patients with a mean coronary artery calcium score of 506, there was an inverse relationship between coronary calcification and accuracy of stenosis detection with MDCT. In all patients, the sensitivity for stenosis detection was 72% and specificity was 97%. When individuals with coronary artery calcium scores >1000 were excluded, the sensitivity and specificity rose to 98% for both. In addition to evaluation of coronary artery segments by MDCT, the investigators in this study also examined per-patient characteristics of coronary MDCT. When an individual was examined as a whole

for the presence or absence of a significant obstructive stenosis, the correct identification of significant coronary artery stenosis could be made in 97% of patients.

The largest and most successful study utilizing 16-detector row MDCT prospectively evaluated 103 consecutive patients undergoing both invasive coronary angiography and coronary CTA.¹⁶ On a per-segment-basis, the sensitivity, specificity and positive and negative predictive value of MDCT was 95%, 98%, 87%, and 99%, respectively. On a per-patient basis, the positive predictive value increased to 98%.

Raff and colleagues published the first study of the diagnostic accuracy of 64-detector CT scanners.¹⁷ They

studied 70 individuals, examining the exactness by which 64-detector CT scanners could correctly classify coronary artery lesions on a per-segment, per-vessel, and per-patient analysis. In comparison to quantitative coronary angiography, Raff's group reported sensitivity, specificity, and positive and negative predictive values on a per-patient analysis of 90%, 95%, 93%, and 93%, respectively. In a careful analysis of mitigating variables in MDCT angiography, higher coronary artery calcium burden, increasing body mass index, and faster heart rate were associated with worsening scan quality and reduced accuracy of detection of significant coronary artery disease (Figure 3).

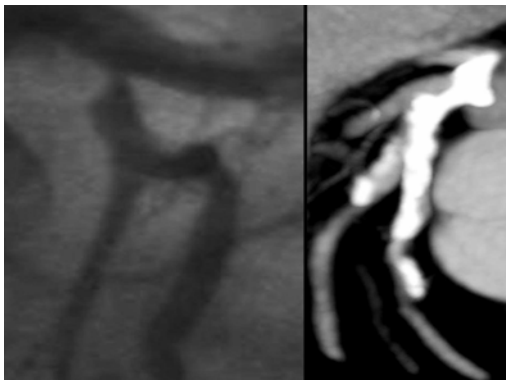


Figure 3. Heavily calcified coronary arteries preclude accurate assessment of coronary stenosis (right hand panel). Coronary angiography (left hand panel) shows no obstruction in area of heavy calcification, but a tight proximal lesion, not seen on CTA, is present in the proximal segment

Since Raff's initial investigation with 64-detector row CT, several other studies have been published examining MDCT against conventional coronary angiography.¹⁸⁻²³ With one lone exception, the sensitivity, specificity and negative predictive value of these studies have well exceeded 90%. It has now become widely accepted that current generations of CT scanners are highly accurate in the detection of obstructive coronary stenosis.

These landmark studies and others examining the accuracy of coronary CTA are important and share many lessons. In chronology, the sensitivity, specificity, and positive and negative predictive values of high-detector row MDCT for the identification of obstructive coronary artery stenosis demonstrated improvement over time. It is likely that this progression in test performance is due, in part, to a learning curve that is intrinsic to the use of any new and developing technology. Moreover, the increased volume coverage with 64-row versus 16-row scanners results in much less cardiac motion misregistration artifact, thereby permitting enhanced diagnostic accuracy. Another lesson learned is that higher calcium scores result in reduced accuracy for detection of stenosis. This is likely explained by partial volume averaging of calcium which results in decreased MDCT accuracy compared to QCA. Furthermore, the importance of low heart rate and normal body mass index for enhanced accuracy

has been reliably demonstrated in these investigations. It is noteworthy to

mention that these studies uniformly included only individuals undergoing subsequent invasive coronary angiography. Therefore, the extrapolation of these results to individuals without a clinical indication for cardiac catheterization may not necessarily be appropriate. Indeed, individuals without a clinical need for conventional coronary angiography (and thereby with a lower pre-test likelihood of coronary artery disease) might likely possess lower levels of calcific coronary plaque such that the accuracy of coronary CTA in these individuals may be enhanced.

While deemed "uncertain" for appropriate use by the recently introduced guidelines, MDCT coronary angiography has nonetheless been extensively evaluated for the assessment of patients with coronary artery bypass grafts (CABGs) as well as those with intracoronary stents. Given their generally larger size and minimal mobility, coronary artery bypass grafts are theoretically easier to image than native coronary arteries (Figure 4).

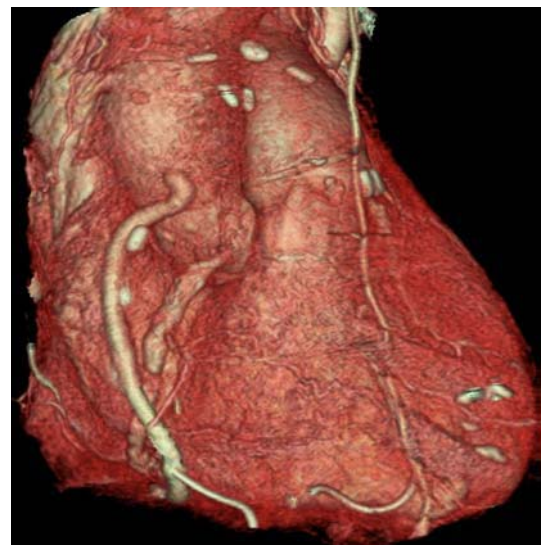


Figure 4. Three-dimensional volume rendered image of a patient following coronary artery bypass grafting, patent vein graft from the aorta to the right coronary artery (VG), and patent but small left internal mammary graft to the left anterior descending coronary artery. (LIMA)

In a systematic review of 985 patients with 2200 bypass grafts, 16-slice MDCT angiography demonstrated 99% sensitivity and 98% specificity for the detection of bypass graft patency.²³ Moreover, MDCT angiography identified significant bypass graft stenoses with 88% accuracy.

In patients who have undergone coronary artery bypass grafting who require repeat operation, MDCT angiography is useful for evaluation of grafts not only for patency but also for surgical planning. In a small study of fifteen patients, MDCT angiography delineated significant narrowings of the internal mammary arteries, adherence of vascular and cardiac structures to the sternum and severity of calcifications



of the aorta.²⁴ These findings resulted in the cancellation of two patients in whom a re-operation was considered to be associated with unnecessarily high risk. In a larger study of 202 patients, MDCT angiography was useful in determining the mean distances of the internal mammary artery grafts to the sternum at three points that traversed the thoracic cavity.²⁵

These important findings prior to repeat operations are easily depicted by noninvasive MDCT angiography.

Intracoronary stents have also been evaluated using MDCT angiography. Different intracoronary stents exhibit different partial volume averaging effects. When 111 consecutive stents were evaluated in 65 individuals utilizing a 40-slice MDCT scanner, detection of moderate or severe restenosis was associated with a sensitivity, specificity, and positive and negative predictive values of 88.9%, 80.6%, 47.1%, and 97.4%, respectively²⁶ (Figure 5).



Figure 5. CTA of intra-coronary stent showing no in-stent restenosis and good distal run-off

In a similar study evaluating 51 individuals with coronary stents and utilizing 16-slice MDCT angiography, the sensitivity, specificity, and positive and negative predictive value for the assessment of $\geq 50\%$ restenosis of an intracoronary stent were 88.3%, 98.5%, 83.3%, and 97.3%, respectively.²⁷

MDCT coronary angiography has also been studied in patients with stable angina pectoris. In a study of 128 patients with stable angina scheduled for invasive coronary angiography, Mollet et al. focused on "revascularizable" coronary segments, or those $> 2\text{mm}$ in diameter.²⁸ In this group, there were 18 obstructive lesions identified by QCA, of which 14 were identified by MDCT. Of the four coronary lesions not correctly identified, two lesions exhibited severe calcification and two exhibited significant motion artifact. The sensitivity, specificity, and positive and negative predictive value of 16-detector coronary CTA for

the detection of significant stenosis were 92%, 95%, 79%, and 98%, respectively.

Given MDCT angiography's value for the detection of significant CAD, some groups have proposed the combination of MDCT coronary anatomic evaluation with stress test functional evaluation. While no current studies currently exist that examine the incremental diagnostic benefit of MDCT coronary angiography following stress testing, the practice is nonetheless becoming commonplace. As noted in recent guidelines, MDCT angiography is considered appropriate for use in stress tests considered to be equivocal or suspected to be inaccurate. Direct comparison of combination MDCT and stress testing to either modality alone is necessary to further delineate the role of either in the evaluation of patients at risk for coronary heart disease.

Current use of MDCT coronary angiography has been primarily limited to symptomatic individuals. Non-invasive coronary evaluation by way of stress testing is commonly employed for cardiac risk stratification in high-risk asymptomatic individuals undergoing non-cardiac surgery. MDCT coronary angiography is finding increasingly use in this patient population, and may provide a better evaluation of overall coronary plaque burden in the patient undergoing surgery. Recently, fifty-five consecutive patients with severe aortic stenosis were evaluated with 16-slice MDCT prior to coronary angiography.²⁹ In this study, the sensitivity of detecting significant stenosis was 100% compared to invasive coronary angiography. Comparing the sensitivities with high (>1000) and low (<1000) calcium scores, MDCT could permit avoidance of conventional angiography in 80% of low-calcium cases but in only 6% of high-calcium cases. From these data, the authors concluded that MDCT may serve as an alternative to conventional cardiac catheterization in patients undergoing elective aortic valve replacement.

To this point, the discussion of the use of coronary CT angiography has focused primarily on the detection of coronary artery disease. The use of contrast-enhanced CT angiography for the demarcation of anomalous coronary artery origins and courses has been well validated as early as the introduction of the 4-slice CT scanners (Figure 6).



Figure 6. Anomalous origin of the left coronary artery

In perhaps the largest review of 1758 individuals who had undergone either 4- or 16-detector coronary CT angiography, 28 individuals (1.6%) were found to have coronary artery anomalies.³⁰ Of these patients, 13 anomalies were considered “malignant” forms because of their path between the aortic root and pulmonary trunk. The majority of these “malignant” anomalies were of the right coronary artery (11 of 13). MDCT coronary angiography is superior to conventional cardiac catheterization for the identification of coronary artery anomalies, as 11 of 20 invasive angiograms performed on individuals suspected of having coronary artery anomalies either resulted in inadequate cannulation of the anomalous artery or ability to render a definitive diagnosis.

MDCT angiography may be useful for the delineation of other congenital abnormalities.

Certain atrial septal defect types, such as sinus venosus defects, are sometimes not well visualized by echocardiography. CT angiography has been shown effective in identifying atrial septal defects of varying types as well as for delineating their borders in patients undergoing percutaneous closure³¹ (Figure 7).

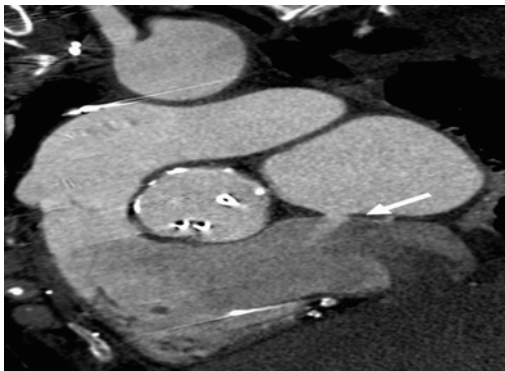


Figure 7. Ostium secundum atrial septal defect. Arrow shows communication between left and right atria

Perhaps the greatest hope for MDCT angiography in the evaluation of patients presenting with chest pain is the “triple rule out” of acute coronary syndrome, pulmonary embolism and thoracic aortic dissection.

While no formal investigations to date have evaluated the accuracy of MDCT angiography for this collective purpose, MDCT has nonetheless been demonstrated to be highly accurate in the detection of both pulmonary emboli and aortic dissection. The PLOPED II investigators evaluated 824 patients with 4-, 8- and 16-slice MDCT scanners. Excluding MDCT scans of poor image quality, the sensitivity and specificity of MDCT for the diagnosis of pulmonary emboli was 83% and 96%, respectively.³² When combined with venous phase imaging, the sensitivity increased to 90% with specificity remaining constant at 95% (Figure 8).

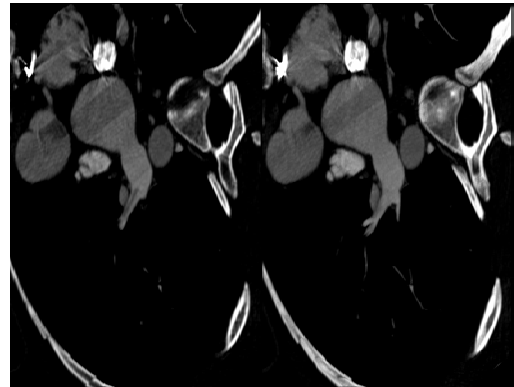


Figure 8. CT pulmonary angiogram showing thrombus within the pulmonary arteries

Similarly, even with the use of older-generation CT scanners, the sensitivity for the detection of acute aortic dissection has been high, ranging between 88-100%.³³

Cardiac MDCT angiography may also be employed for evaluation of cardiac structure and function. In this vein, MDCT angiography may have great potential in the evaluation of individuals presenting with new-onset heart failure. MDCT angiography can provide comprehensive assessment of left and right ventricular ejection fraction and volume as well as determining the extent of coronary artery disease. This may render this modality useful for the distinction between ischemic and nonischemic cardiomyopathies. Although systemic evaluation of cardiac CT has not yet been performed for the distinction of non-ischemic versus cardiomyopathy, it is not unreasonable to consider its use. In the absence of significant left main, proximal left anterior descending, or three-vessel coronary artery disease, the physician may be able to confidently conclude that ventricular dysfunction may be due to a cause other than coronary artery disease.

In our own laboratory, we reconstruct twenty phases of the cardiac cycle in 5% increments of the R-R interval. Using this protocol, appraisal is possible for both overall ventricular systolic function as well as for segmental wall motion. The accuracy of MDCT cardiac imaging for these purposes has been well validated. Cardiac MDCT imaging has been compared to cardiac magnetic resonance imaging (MRI) and echocardiography.³⁴ In a study of 52 patients, the correlation between MDCT and MRI was high for left ventricular end diastolic volume ($r=0.83$), left ventricular systolic volume ($r=0.90$), ejection fraction ($r=0.88$), and myocardial mass ($r=0.84$). The correlation of echocardiography to MRI was low for left ventricular end diastolic volume ($r=0.05$), end systolic volume ($r=0.59$) and ejection fraction ($r=0.24$). These data suggest that cardiac MDCT imaging may be more useful for evaluation of ejection fraction in individuals and thus, may be considered in the evaluation of individuals with technically limited echocardiograms.

In a binary analysis of 616 myocardial segments for the presence or absence of segmental wall motion abnormalities,



there was an 89% agreement between MDCT cardiac imaging and transthoracic echocardiography.³⁵ In this study, only five phases of the cardiac cycle (0%, 40%, 50%, 70%, and 80%) were reconstructed. It is undoubtedly true that agreement between MDCT and echocardiography would be enhanced by the addition of more phases of the cardiac cycle. A potential advantage of cardiac MDCT over transthoracic echocardiography in the evaluation of individuals with heart failure may lie in the enhanced ability of MDCT to visualize both the left and right ventricles. As the right ventricular size and function has historically been difficult to assess with echocardiography, identification of a noninvasive method for quantifying function of both ventricles accurately may be valuable to understand an individual's heart failure etiology as well as to guide its treatment. In a study of twenty patients evaluated by both MDCT cardiac imaging and first-pass radionuclide angiography, agreement between methods was good ($R=0.854$, $p=0.001$) with

reconstructions of only two phases of the cardiac cycle.³⁶ Moreover, MDCT cardiac imaging was able to provide right ventricular end-diastolic and end-systolic volumes as well as right ventricular mass, which is not possible with radionuclide angiography.

Cardiac MDCT angiography is also useful for evaluation of non-coronary cardiovascular anatomy. It is well documented that muscular tissue within the pulmonary veins are often the origin of arrhythmogenic foci that serve as an important cause of atrial fibrillation.^{37,38} Numerous surgical and more recently, percutaneous techniques have been developed to disconnect electrically the pulmonary veins from the left atrium, thereby providing a cure to the arrhythmia. As the anatomy of pulmonary vein is different amongst individuals, noninvasive imaging of the pulmonary veins and left atrium in individuals prior to atrial fibrillation ablation is essential (Figure 9).

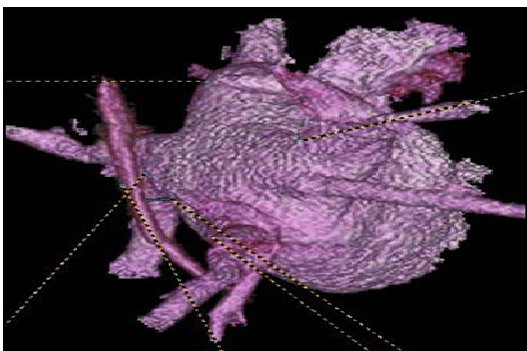


Figure 9. CTA image of the left atrium and pulmonary veins

Specific examples of pulmonary vein variation include a common left or right pulmonary vein (in 2.4-25% of individuals imaged) as well as accessory pulmonary veins.^{39,40} These findings have obvious implications at the time of ostial segmental pulmonary vein isolation. MDCT

cardiac imaging has been embraced with increasing use for the three-dimensional reconstruction of pulmonary veins and left atrium. In our own laboratories, we routinely create MDCT renderings of left atria and pulmonary veins in patients prior to segmental pulmonary vein isolation. These pulmonary vein and left atrium surface-shaded three-dimensional models are created using CardEP software (GE Healthcare, Milwaukee, WI) or EBW software (Philips Medical Systems, Cleveland, Ohio) and can be easily merged with the Carto™ electroanatomic mapping system (Figure 10).

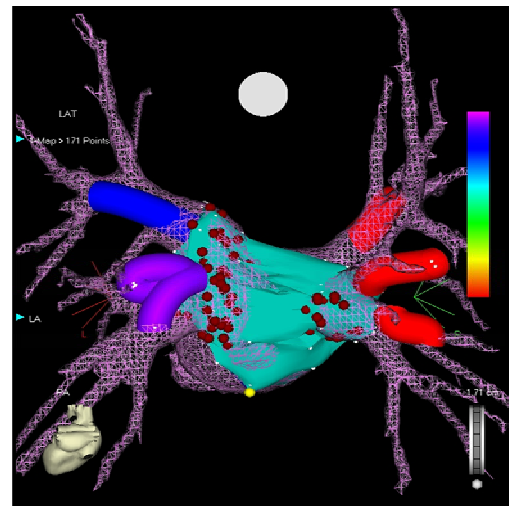


Figure 10. CTA image of the left atrium and pulmonary veins superimposed on the electrophysiologic mapping grid used for catheter ablation of atrial fibrillation

In this way, pulmonary vein ostial diameters as well as their length to first branchpoint can be easily measured. The fusion between the CT and electroanatomic data results in an accuracy to 2.1 mm in distance between the mapping points and the MDCT surface.⁴¹

New developments in software technology now permit co-registration of three-dimensional surface-shaded cardiac MDCT images with projection images acquired by fluoroscopy. In twenty patients placed in the same position, co-registration of MDCT images and fluoroscopic images of the left atrium demonstrated a mean registration error of only 1.4 mm.^{42,43} This technique will undoubtedly result in improved navigation and localization of intracardiac catheters during atrial and ventricular arrhythmia ablations.

MDCT cardiac imaging is also useful for evaluation of the left atrial appendage for the presence or absence of thrombus.⁴⁴ Prior studies utilizing older generation scanners with inferior temporal resolution have demonstrated MDCT's ability to identify thrombus. With current generation 64-slice MDCT scanners with improved temporal resolution, thrombus as well as thrombus-in-formation (non-clearing spontaneous echo contrast) can be successfully identified (Figure 11).



Figure 11. CTA showing left atrial thrombus (arrow)

Focal pulmonary vein stenosis as a complication of atrial fibrillation ablation is widely recognized, occurring as a result of hyperplasia of the venous vascular wall.⁴⁵ MDCT cardiac imaging can reliably demonstrate focal pulmonary vein stenosis and is useful for the follow-up of patients who develop symptoms after atrial fibrillation ablation.

The coronary venous system is being increasingly utilized for percutaneous treatment of patients with advanced left ventricular systolic dysfunction. The coronary sinus and lateral marginal veins are often cannulized with a transvenous lead in the placement of biventricular pacemakers in patients with mechanical dyssynchrony. Successful placement of the transvenous left ventricular lead in an appropriate location within the coronary venous system is estimated to be 88-95%.⁴⁶

This number may be lower in less experienced institutions and underscores the fact that 5-12% of individuals will undergo an invasive procedure without successful lead implantation. MDCT angiography can successfully define coronary vein anatomy prior to any invasive procedure.⁴⁷ In 38 individuals, MDCT angiography has been shown to be successful for the illustration of the coronary sinus and its tributaries. In these individuals, identification of coronary vein variants were noted, including separate insertion sites of the coronary sinus and cardiac veins, linking the anterior and posterior coronary veins at the crux cordis, and incomplete connection of the posterior vein to the contrary sinus. These findings may provide explanations in cases where successful left ventricular lead implantation via the coronary sinus cannot be achieved or aid in the pre-procedural planning of where a left ventricular lead is to be placed.

Similar hybrid imaging systems are being developed to use CTA mapping of the coronary arteries in the cardiac catheterization laboratory to assist in performing real time angiography. Coronary CTA, inherently three dimensional, is useful in selecting angiographic views and avoiding foreshortening artifacts present in silhouette imaging

produced by conventional fluoroscopy.

Conclusion

With the introduction of current generation scanners which can provide rapid volume coverage with improved spatial and temporal resolution, the utility of MDCT for cardiac and coronary imaging is experiencing exponential growth. MDCT angiography of the coronary arteries is useful for the evaluation of symptomatic individuals with and without known coronary artery disease, with high accuracy. The utility of MDCT cardiac imaging extends to non-coronary indications that aid the cardiac specialist in applications of electrophysiology, echocardiography, heart failure, and nuclear cardiology. The evolution of MDCT has been rapid; further evidence supporting these and many more applications can be expected, as investigators in many centers around the world are excited by the many opportunities for clinical research presented by this new technology.

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