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Cardiovascular Applications of Volume CT

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LEARNING OBJECTIVES

Upon completion of this activity, participants should be able to:

1. Describe the principles involved in cardiovascular CTA.
2. Understand protocols and risks of cardiovascular CTA.
3. Identify clinical settings in which cardiovascular CTA may be useful.
4. Explain some of the relative merits of cardiovascular CTA compared to other diagnostic modalities.

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Dr. Raman has no significant financial arrangement or affiliation with any manufacturer of any pharmaceutical or medical device and is not affiliated in any manner with any provider of any commercial medical or healthcare professional service.

Cardiovascular disease is the leading cause of death worldwide.[1] Addressing this epidemic requires improvements in diagnosis and prevention as well as continued therapeutic advances. Historically, noninvasive imaging in cardiovascular disease has relied on modalities such as ultrasound and nuclear scintigraphy. With the achievement of rapid volume CT as a clinical reality, cardiovascular medicine has a tremendously powerful new diagnostic tool.

TECHNIQUE

Volume CT is defined as coverage of a volume of interest with a single CT acquisition. While single-slice spiral CT covers multiple adjacent slices with each rotation of the gantry, a "volume" of interest can be acquired only with multiple rotations. Volume CT takes advantage of multislice technology's use of 64 or more detector elements along the z (patient)-axis. Thus, with one rotation of the gantry, a volume of contiguous transaxial data is generated along the length of the detectors.[2]

PROTOCOLS

At the time of scheduling, screening for renal insufficiency or contrast allergy facilitates protocol selection and patient preparation. As with invasive angiography, there is almost no absolute contraindication to the procedure, provided that potential risks are recognized and weighed against potential benefits. One contraindication, however, is obesity morbid enough to preclude the

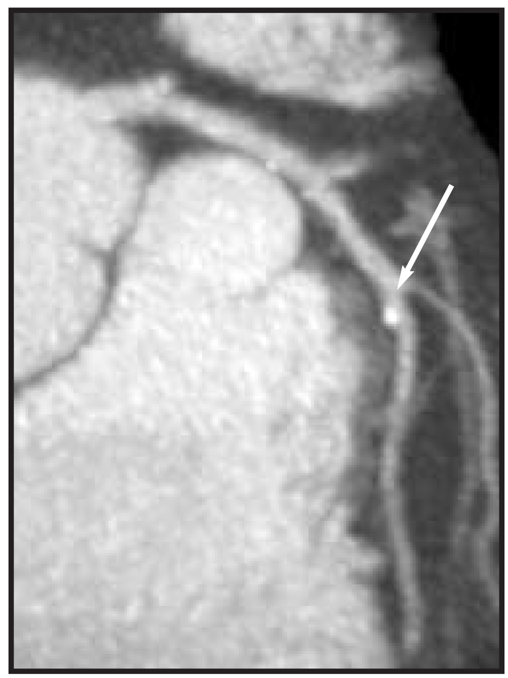

Figure 1. Nonobstructive plaque (arrow) visualized in the left circumflex coronary artery in a patient referred for coronary CT angiography after stress nuclear imaging performed for atypical chest pain demonstrated inferior attenuation artifact.

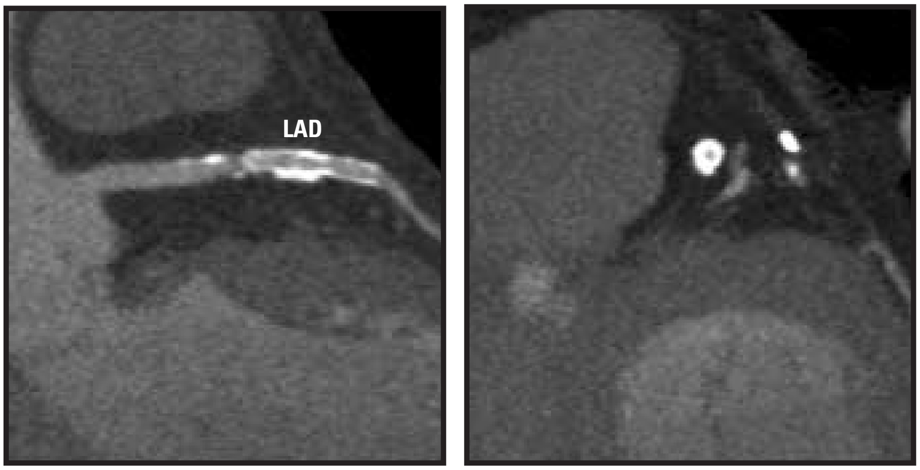

Figure 2. Patent proximal left anterior descending artery (LAD) stent demonstrated lengthwise (left) and in cross-section (right).

patient's entry into the scanner. Most systems can accommodate patient weights of up to 400 pounds; soft tissue attenuation increasingly reduces image quality for patients weighing more than 250 pounds.

To illustrate the balance of risk and benefit in renal insufficiency, consider assessment of the patient with acute nonoliguric renal failure and elevated troponin of possible cardiac origin. Evaluation in this case requires carefully weighing the potential risk of worsening renal function and the possible need for dialysis against the need to define the coronary anatomy. Such patients also have acute coagulopathies due to renal dysfunction, particularly platelet dysfunction, which may also increase the risks associated with invasive angiography. More aggressive preprocedure hydration as tolerated with meticulous monitoring of urine output postprocedure has long been used to safely guide such patients through invasive angiography, and can be similarly employed for noninvasive CT angiography. Premedication with steroids and antihistamines in conjunction with use of appropriate contrast media allows patients with contrast allergy to more safely undergo both invasive and noninvasive angiographic procedures. This also requires staff training and adequate postprocedure monitoring to facilitate recognition and treatment of allergic reactions, should they occur.

All volume CT protocols share some common elements of patient preparation. Having patients fast for at least two hours before the procedure minimizes the risks of aspiration in the event of contrast-induced nausea and vomiting. Most systems currently in clinical use perform best when the heart rate is 70 beats per minute or lower, with essentially no artifacts due to cardiac motion in this range; however, adequate image quality can occasionally be obtained with higher heart rates. Optimal heart rate can be readily achieved with oral or parenteral administration of a beta blocker, which is well tolerated in most patients with adequate screening for drug intolerance or severe airway obstruction. Not only does the beta blocker help reduce heart rate; it also blunts heart rate increase that may result from breath-holding and rapid infusion of intravenous contrast material. Nursing support is key to administering beta-blocking medication when the patient presents to the imaging facility, with documentation of vital signs before and after IV drug administration required. Ideally, notification by the referring physician that the patient's heart rate typically runs above 70 bpm will prompt prescription of an oral beta blocker to be taken one hour prior to the procedure.

After the patient is placed on the scanner table, simple skin preparation ensures the electrodes adhere adequately to the chest to record the electrocardiographic signal needed for ECG-gated acquisitions. The technologist instructs the patient on the brief breath-hold that will be required during the volume scan and optimizes the patient's position on the table for isocentering. The volume of coverage prescribed depends on the patient's history; for most studies, scanning from just below the carina to just below the base of the heart will cover the cardiac anatomy for coronary artery imaging. For patients with a history of coronary artery bypass grafting, the aortic anastomoses should be included in the volume by including more cranial coverage; we routinely start above the clavicle in patients with a history of bypass surgery and an internal thoracic artery graft, or in cases where the operative report is not available. For patients with only saphenous vein and free arterial conduits, prescribing the volume to begin at least 3 to 4 cm above the carina should provide adequate coverage to visualize the aortic anastomoses of these grafts.

The majority of cardiovascular acquisitions require timing optimized for appearance of contrast in the arterial side of the system. This may be accomplished with a timing bolus scan using a small volume of contrast and rapid, repeated imaging of a single transaortic plane to determine the time between peripheral contrast injection and appearance of contrast in the aorta. Alternatively, a Hounsfield unit threshold may be set such that the volume acquisition is triggered to begin once a certain signal intensity is detected in the ascending aorta. For studies of the venous system, such as definition of the cardiac venous anatomy prior to biventricular pacemaker placement or imaging of the coronary arteries, in patients whose great arteries are transposed, the region of interest for timing should be placed in the pulmonary artery or pulmonary vein. Additionally, a lower signal intensity threshold may provide sufficient contrast opacification to image both arterial and venous sides of the cardiovascular system.

Scanning itself, with rapid gantry rotation and z-axis coverage, requires very little time on today's volume CT scanners. The volume scan itself takes 10 to 20 seconds with intravenous administration of 80 to 100 cc of contrast material. Once completed, the patient should be monitored briefly and given additional information regarding symptoms of contrast reaction and instructions for follow-up after discharge from the imaging facility. The technologist and interpreting physician then generate reformatted images of the structures of interest; the time to generate at least a preliminary report should be no more than 20 minutes with coordinated efforts of the team and adequate availability of workstations for postprocessing and review. Image review varies based on the interpreting physician's preference, and may be coronary segment-based or imaging plane-based; in general, a combination of surface or volume reconstructions with 2D multiplanar reformats or maximal intensity projections allows both global visualizations and assessment of structures of interest. Examination of prior studies by the interpreting physician allows the results to be reported in the context of the patient's history. Recent stent placement in a coronary segment, for example, should prompt comparison of volume CT images with the angiograms obtained postintervention to determine what, if any, interval change has occurred. This additional time and effort ensures that the final report will provide value in clinical decision-making.

CLINICAL VALUE

The highest clinical value of volume CT is delivered by incorporating the individual patient's history and referring clinician's questions into protocol design. For example, one source of referrals at our institution consists of patients with atypical chest pain and indeterminate results on stress testing. The clinical question in this scenario is: Does this patient have epicardial coronary artery stenosis, which is causing the symptoms? The protocol in this setting should focus on visualizing the contrast-enhanced epicardial coronary arteries (Figure 1). Other referrals may seek assessment of coronary atherosclerosis in an asymptomatic patient with risk factors that do not necessarily mandate medication therapy. In such cases, noncontrast volume CT may suffice to define the presence and extent of coronary artery calcification. Coronary calcium identified by noncontrast volume CT is direct evidence of coronary atherosclerosis and should prompt aggressive secondary prevention measures.

As alluded to in the previous section, bypass graft and stent patency can be reliably assessed with volume CT. In-stent restenosis may appear as an absence of contrast in that section or a focal filling defect; reformatting the axial data to produce cross-sectional images through the stent further refines the ability of volume CT to determine stent patency (Figures 2 and 3). Bypass grafts are often easier to visualize than native coronary artery segments due to their larger size and reduced motion. In a study comparing volume CT to invasive angiography, the sensitivity to detect graft stenosis was 97%, specificity 100%, and overall diagnostic accuracy 99%.[3]

With careful operative history and clear definition of the volume of coverage during scanning, patients with a history of bypass surgery should no longer have to undergo invasive angiography unless presenting with unstable signs or symptoms. Even in such cases, the speed of acquisition when pretest probability of cardiac source of symptoms is low or intermediate may motivate the use of volume CT to avoid invasive angiography and its attendant risks.

Volume CT can also be used to answer a variety of other cardiovascular questions, limited only by the willingness of the referring clinician to consider alternative diagnostic strategies and the creativity of the volume CT physician in designing a protocol to answer their questions. For example, patients with aortic stenosis are routinely referred for invasive angiography to define the coronary anatomy prior to open-heart surgery for valve replacement. Echocardiography occasionally underestimates the gradient and therefore degree of stenosis, or overestimates stenosis severity, even with transesophageal measurements of valve area and risks of esophageal intubation. Volume CT can adequately define the epicardial coronary anatomy, and recent work suggests that it can also confirm the severity of stenoses by direct planimetry of the valve,[4] thus providing the necessary information for surgical planning. Other cardiovascular uses of volume CT include definition of the pulmonary venous anatomy prior to radio-frequency ablation for atrial fibrillation, delineation of the cardiac veins prior to biventricular pacemaker implantation, and postimplant assessment of intracardiac devices.[5] While it is unlikely to be the sole reason for referral for a volume CT examination, multiphase reformatting of volume CT data can provide quantification of ventricular volumes and function, particularly when conflicting data from other modalities exist and there is a concomitant need to define the coronary arteries or other complex cardiovascular anatomy.[6,7]

COMPARISONS TO ALTERNATIVE PROCEDURES

As most referrals for cardiovascular CT are for coronary angiography, the comparative procedure is catheter-based invasive x-ray angiography. There is no question that the current resolution of digital flat-panel x-ray imaging systems is far superior to that of volume CT; that is why this procedure remains the gold standard for coronary angiography and intervention. However, the question is not which modality provides higher resolution, but rather what resolution

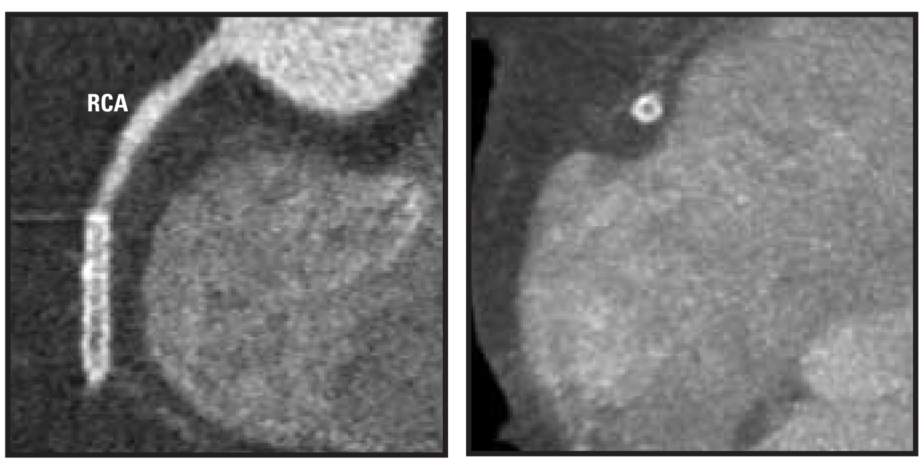

Figure 3. Occluded right coronary artery (RCA) stent. Note absence of contrast within lumen of stent.

is needed to answer the clinical question and allow proper diagnosis and treatment selection. Multiple recent publications have placed the accuracy of 16-detector-row CT angiography to identify epicardial coronary stenoses at between 90% and 100%.[8] This can only be expected to improve with the faster acquisition speed and resultant lower cardiac motion-induced artifact with volume systems using 64 or more detector rows. Coronary calcification poses a unique challenge for all systems; mild calcification does not prevent luminal assessment, but severe calcification can cause poor visualization of the lumen of a given segment, precluding assignment of a stenosis percentage. As high-grade localized calcification may indicate high-grade stenosis, the presence of such should prompt either stress testing—to assess the physiological significance—or invasive angiography, depending on the clinical setting.

A few words on stress testing are warranted at this point. Stress testing will identify abnormalities only in the setting of 70% or greater stenosis in an epicardial coronary artery or graft segment. Stress testing, therefore, should not be considered a way to detect the presence and anatomic extent of atherosclerosis but rather a test for myocardial ischemia, exercise capacity, and other functional assessments. In certain clinical instances, the physiological information from stress testing may complement the anatomic information provided by volume CT. In other cases, such as in a patient with recent bypass grafting and recurrent atypical chest pain, the clinician simply wants to know whether the grafts are patent. To answer this, volume CT is sufficient.

Cardiovascular MRI is an excellent diagnostic modality for not only cardiovascular anatomy but also physiological assessment, including myocardial perfusion, viability, and flow measurements. CMR is certainly superior to echocardiography and nuclear scintigraphy for ventricular quantification and scar visualization, making it the modality of choice for determining myocardial viability and function.[9,10] For coronary artery imaging, however, CMR lags behind volume CT in consistent visualization of all segments of the coronary tree. And currently used coronary stents produce signal artifact on MR images preventing visualization of the intrastent lumen. Advances in higher field angiography and the use of intravascular MR contrast agents may narrow the gap, or MR techniques may become preferred for plaque characterization, given MR's greater contrast between different tissue types. While MR's ability to generate images without the use of ionizing radiation is appealing, consider that volume CT for cardiovascular diagnosis requires no more radiation than that used by routine abdominal and pelvic CT imaging to assess postcatheterization retroperitoneal bleeding, and is only slightly higher in radiation dose than conventional x-ray coronary angiography.[11] For now, volume CT affords rapid, reliable imaging of the coronary arteries and conduits with a degree of accuracy not yet matched by MR angiography.

CONTRIBUTION TO PATIENT DIAGNOSIS/MANAGEMENT

Ultimately, selection of effective therapeutic strategies for individual patients requires accurate diagnosis and minimized patient risk. Volume CT has made noninvasive coronary angiography a clinically viable option for patients and their physicians, and can provide high-resolution cardiovascular diagnostics in many areas beyond coronary artery imaging. Developers of volume CT have striven toward a fundamental goal in medical technology development: to improve patient care without complicating it. By providing a robust noninvasive technique that yields high-resolution cardiovascular diagnostic information with little patient risk, volume CT achieves this goal. ■

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REFERENCES

1. *Heart disease and stroke statistics—2004 update.* American Heart Association, Dallas, TX, 2003.
2. Flohr TG, Schoepf UJ, Kuettner A, et al. Advances in cardiac imaging with 16-section CT systems. Acad Radiol 2003; 10(4):386-401.
3. Schlosser T, Konorza T, Hunold P, et al. Noninvasive visualization of coronary artery bypass grafts using 16-detector row computed tomography. J Am Coll Cardiol 2004;44(6):1224-1229.
4. Jardin C, Bouvier E, Sablayrolles J. Comparison of multislice CT with echocardiography for the diagnosis and quantification of aortic stenosis. Proceedings of 5th International Conference on Cardiac Computed Tomography, Nuremberg, Germany, 2004.
5. Cook SC, McCarthy M, Daniels CJ, et al. Usefulness of multislice computed tomography angiography to evaluate intravascular stents and transcatheter occlusion devices in patients with d-transposition of the great arteries after mustard repair. Am J Cardiol 2004;94(7): 967-969.
6. Juergens KU, Grude M, Maintz D, et al. Multi-detector row CT of left ventricular function with dedicated analysis software versus MR imaging: initial experience. Radiology 2004;230(2): 403-410.
7. Raman S, Cook S, McCarthy M, Ferketich A. Usefulness of multi-detector row computed tomography to quantify right ventricular size and function in adults with either tetralogy of Fallot or transposition of the great arteries. Am J Cardiol 2005: in press.
8. Ropers D, Baum U, Pohle K, et al. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation 2003;107(5): 664-666.
9. Pennell DJ, Sechtem UP, Higgins CB, et al. Clinical indications for cardiovascular magnetic resonance (CMR): Consensus Panel report. Eur Heart J 2004;25(21):1940-1965.
10. Lima JA, Desai MY. Cardiovascular magnetic resonance imaging: current and emerging applications. J Am Coll Cardiol 2004;44(6):1164-1171.
11. Bae KT, Hong C, Whiting BR. Radiation dose in multidetector row computed tomography cardiac imaging. J Magn Reson Imaging 2004;19(6):859-863.

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