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OVERVIEW OF CARDIAC IMAGING WITH COMPUTED TOMOGRAPHY AND MAGNETIC RESONANCE

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Annotation: Cardiac computed tomography (CT) and cardiovascular magnetic resonance (CMR) imaging have emerged as options for noninvasive evaluation of the heart in clinical practice. Coronary CT angiography (CCTA) represents a widely available and well-tolerated examination which visualizes the presence and extent of coronary artery disease (CAD) noninvasively both in the acute and nonacute setting. CMR with morphologic and functional assessment is used to diagnose both ischemic and nonischemic cardiomyopathy, myocarditis, valvular, and pericardial disease. Both cardiac CT and CMR are tomographic imaging technologies.

Key words: Contemporary practice, computed tomography, magnetic resonance, Nitroglycerin, sublingual tablet or spray.

Patient selection for CCTA — CCTA is used to detect obstructive CAD in patients with stable angina as well as in patients with acute coronary syndrome.

***Detection of obstructive CAD* —** Among available noninvasive tests, CCTA has the highest diagnostic accuracy for the detection of obstructive CAD defined as >50 percent luminal narrowing in major epicardial vessels as detected by invasive coronary angiography. Especially because of its high sensitivity and corresponding low rate of false negatives, CCTA is a test best suited to identify patients at low risk for future major adverse cardiovascular events (MACE). The ideal patient for CCTA would have an intermediate pretest probability (10 to 90 percent) for significant CAD (as defined by the Diamond-Forrester score) in whom diagnostic assessment is warranted, but one in whom exclusion of significant CAD is the primary goal of testing.

Pretest probability instruments in use in contemporary practice, including the Diamond-Forrester score, dramatically overestimate (eg, three- to fivefold) the true prevalence of significant CAD in some populations and may lead to CCTA overutilization. Better clinical risk stratification tools under development aim to improve appropriate utilization of CCTA. Choice of CCTA among alternative tests (eg, stress testing or myocardial single photon emission computed tomography) in this setting is discussed elsewhere.

***Prognostic value of CAD* —** CCTA not only detects the presence and extent of stenosis but also coronary plaque. Overall, the presence and extent of both aspects of CAD are strong predictors for future MACE [18]. For example, the absence of any CAD on CCTA carries a warranty period of up to five years for a very low risk (<0.2 percent) of MACE, while the presence of nonobstructive and obstructive CAD carries a three- and sixfold increased risk of future MACE over five years compared with those without these findings. Thus, the test findings can be used to guide subsequent management by diagnosing obstructive CAD for potential revascularization procedures and by assessing prognosis for antiatherosclerotic medical therapy.

Acute coronary syndrome — In patients with intermediate or low probability of acute coronary syndrome, early CCTA is an effective test to exclude the diagnosis [10,11]. Absence of CAD on

CCTA is associated with an at least two-year period with very low risk of MACE [12]. The choice of CCTA among other management alternatives (eg, stress testing and coronary artery catheterization) in this setting is discussed elsewhere.

CCTA imaging protocol — CT scanners with high spatial and temporal resolution are necessary for image acquisition, as imaging is tailored to accurately visualize the presence and extent of CAD, primarily by minimizing motion artifacts. A 64-slice multidetector technology is considered a minimum standard, with more advanced CT scanners (eg, 128-slice, 256-slice, dual source) capable of rendering better images at lower radiation exposure. Image acquisition is synchronized to the electrocardiogram (ECG). A bolus dose of iodinated contrast (typically 50 to 120 mL) is administered intravenously. Nitroglycerin, sublingual tablet or spray, is given immediately prior to the examination to dilate the coronary arteries and facilitate assessment of luminal narrowing. Typically, a short-acting oral or intravenous beta blocker is administered to slow the heart rate to less than 60 to 70 beats per minute.

Contraindications and adverse effects — The most common contraindication to CCTA is severe renal insufficiency (ie, estimated glomerular filtration rate test <30 mL/min/1.73 m^2) or a history of allergy to iodinated contrast, (eg, anaphylaxis). In this situation, alternative tests (eg, stress testing) or preventive measures to minimize the potential adverse effects of iodinated contrast (eg, premedication for contrast allergy, hydration for renal insufficiency) are available.

Patients must be cooperative and able to hold their breath for 5 to 10 seconds. Cardiac tachyarrhythmias (eg, atrial fibrillation) and excessive motion due to inability to perform a breath-hold can lead to nondiagnostic CCTA examinations, especially with basic 64-slice technology [18].

With the development of dose reduction technology and increased spatial and temporal resolution, the newest CT scanner technology enables high-quality diagnostic CCTA acquisition at median effective radiation doses between 2 and 5 mSv, comparable with one to two years of background radiation (which is about 3.1 mSv at sea level) [15,16]. However, the dose can be significantly higher (up to 12 or 15 mSv) using first generation 64-slice CT scanners or in individual patients (eg, obese, high heart rate).

CCTA diagnostic performance and results reporting

Diagnostic accuracy — CCTA detects luminal narrowing of ≥50 percent diameter with high sensitivity and negative predictive value.

The diagnostic accuracy of CCTA for detection of ≥50 percent diameter stenoses using invasive coronary angiography as the reference standard has been measured in a number of multicenter studies using scanners from multiple vendors [1-3]. CCTA consistently demonstrates a patient-based sensitivity of 95 to 99 percent. However, the specificity of CCTA is variable, ranging from 64 to 90 percent, and is subject to image quality and underlying artifacts from patient factors. For example, in patients with high calcium scores (ie, >400 Agatston units), a specificity as low as 53 percent has been reported [1].

CAD-RADS categories — A standardized radiology reporting system for CCTA (CAD-reporting and data system [CAD-RADS]) has been introduced and endorsed by professional societies [17].

CAD-RADS describes CCTA findings and classifies them according to management recommendations in patients with either acute or stable chest pain.

CAD-RADS categories are:

●CAD-RADS 0 – 0 percent stenosis

●CAD-RADS 1 – 1 to 24 percent stenosis

●CAD-RADS 2 – 25 to 49 percent stenosis

●CAD-RADS 3 – 50 to 69 percent stenosis

●CAD-RADS 4A – 70 to 99 percent stenosis

●CAD-RADS 4B – >50 percent left main or ≥70 percent three-vessel stenosis

●CAD-RADS 5 – 100 percent stenosis/occlusion

●CAD-RADS N – Nondiagnostic examination

Modifiers to each category are sometimes added and include V (vulnerable high-risk plaque), S (stent), or G (graft).

Other cardiac CT applications

Left ventricular function and myocardial perfusion — Cardiac CT can be performed in the same sitting as CCTA to assess left ventricular morphology, function, and myocardial perfusion, potentially increasing specificity of the examination for CAD [18]. CT perfusion requires pharmacological stress and imaging both at rest and with stress. Initial results are promising, but with the availability of alternative tests this examination is limited in use and availability.

Fractional flow reserve — CT-based computational fluid dynamics modeling and simulation of fractional flow reserve (FFR) is an emerging technology intended to improve the specificity for CCTA [20,21]. The CT images are segmented to delineate coronary lumen and myocardium, and mathematical models are applied to simulate pharmacological stress across a stenotic segment. This method demonstrates reasonable agreement with FFR measurements derived from coronary artery angiography [22]. FFR-CT is not universally available and is performed only by sending the CT image dataset to a commercial entity that provides the advanced data analysis.

Cardiovascular magnetic resonance imaging

CMR is the method of choice for assessment of functional and tissue properties of the heart, including atrial and ventricular anatomy and motion, valvular function, myocardial tissue composition, and pericardial disease. The necessary technology and imaging expertise for CMR are available at major medical centers but are subject to geography and associated clinical expertise. (See "Clinical utility of cardiovascular magnetic resonance imaging".)

Patient selection for CMR **—** Patients evaluated with CMR typically have advanced and more complex diseases, and are usually referred after initial testing with first-line technology (ie, transthoracic echocardiography).

CMR imaging protocol **—** The technical requirements, indications [23,24], imaging protocols [18], and reporting of CMR are increasingly standardized and often tailored to each clinical indication.

Generally, a 1.5 Tesla (T) or 3 T CMR unit capable of ECG-gated imaging is utilized. Standard four-chamber and short-axis balanced steady-state free precession cine images are usually acquired from the base of the heart to the apex to assess ventricular wall thickness, mass, and regional/global systolic function. Parametric mapping with native (noncontrast) T1, T2, T2*, and/or postgadolinium extracellular volume fraction imaging are commonly performed [26] in the assessment for cardiomyopathies (eg, amyloid, iron deposition). Phase contrast flow imaging is performed orthogonal to the main pulmonary artery and aorta to directly measure right and left ventricular forward flow, respectively. Flow can also be measured directly across the mitral or aortic valve or through any area of interest (eg, atrial septal defect).

Gadolinium contrast is given if assessment of scar or fibrosis is indicated. Pharmacologic stress perfusion imaging, if indicated and locally available, is performed using either inotropic (eg, dobutamine) or vasodilator (eg, regadenoson, adenosine, or dipyridamole) agents.

CMR use by clinical indication — CMR enables further evaluation of the myocardium for ischemia (eg, perfusion, viability, scar), inflammation, or infiltration (eg, deposition with iron, amyloid, etc). In addition, CMR is used to further evaluate suspected valvular dysfunction (eg, stenosis, regurgitation), the pericardium, suspected cardiac tumors, and coronary artery anatomy.

Stress testing for myocardial ischemia — In patients with suspected CAD, CMR is performed both at rest and after pharmacologic stress, to evaluate for ischemia (dobutamine/wall motion or vasodilator/perfusion deficit).The cine motion of the ventricular walls during systole and diastole is visualized and the chambers can be assessed volumetrically. Vasodilator perfusion CMR is performed with first-pass of gadolinium contrast.

Nonischemic cardiomyopathy — CMR is the preferred imaging examination as a follow-up to echocardiography in patients with suspected nonischemic cardiomyopathy (eg, infiltrative disease, iron deposition, hypertrophic cardiomyopathy, amyloid, etc) to diagnose the underlying etiology and to assess myocardial viability and function. Native T1, T2, T2*, and extracellular volume fraction assessment is often used. In these patients, ischemic cardiomyopathy has already been excluded.

Myocarditis — Acute myocarditis is a diagnostic consideration in patients with chest pain or heart failure symptoms, elevated troponin level and/or non-coronary ventricular dysfunction on

echocardiography, and no clear evidence of underlying cardiac ischemia. CMR often provides supportive evidence of myocarditis when endomyocardial biopsy is not performed.

Valvular disease — Following cardiac echocardiography, CMR enables detailed assessment of valvular motion and enables visualization of flow dynamics for turbulence and quantification of regurgitation.

Pericardial disease — CMR enables direct visualization of the pericardium and is used in suspected underlying pericardial disease such as recurrent pericarditis, thickening/constrictive pericarditis, tumor invasion, and congenital absence of the pericardium. For CMR tagging, spatial modulation of magnetization methods are often used

Cardiac tumor — CMR is the preferred examination for evaluating suspected cardiac tumors or thrombi detected on echocardiography. CMR enables better characterization of the tissue composition and perfusion, as well as improved detection of intracardiac thrombi.

Coronary artery disease — Noncontrast CMR can be used to identify the coronary artery origins and thus avoid the radiation and iodinated contrast associated with CCTA. In addition, no beta blockers are used for coronary artery CMR. However, if CMR is not available or not feasible (eg, contraindications to CMR), CCTA can also be used, as it yields higher-resolution images and comparable diagnostic performance.

Coronary stenosis — Because of limitations in study duration, spatial resolution, and sensitivity to patient motion, CMR is less practical than CCTA for evaluating the coronary arteries. Coronary artery CMR is less accurate than CT in diagnosing clinically significant (≥50 percent) stenoses of the coronary arteries [27,28].

Congenital artery anomalies — The risk of sudden cardiac arrest is increased in patients with congenital coronary anomalies when the proximal segment of an anomalous coronary artery courses between the aorta and the pulmonary artery. In this setting, the anomalous vessel may become compressed, leading to myocardial ischemia and possibly fatal arrhythmias. This is most likely to occur during periods of high cardiac output, as in young athletes and military recruits.

Coronary artery aneurysms/Kawasaki disease — The vast majority of acquired coronary artery aneurysms are due to Kawasaki disease, a generalized vasculitis occurring in infants and young children. Coronary artery aneurysms occur in 20 to 25 percent of patients with Kawasaki disease who are treated with aspirin. In two comparative studies with a total of 19 children, adolescents, and young adults with coronary aneurysms and/or ectasia, CMR was as accurate as conventional invasive coronary angiography in identifying and defining (aneurysm diameter and length) the lesions [18]

Aorta aneurysm, dissection, coarctation — Gadolinium contrast and noncontrast CMR angiography are commonly used for the identification, characterization, and monitoring of known or suspected aortic aneurysm or dissection, as well as localization of aortic coarctation. An advantage of CMR versus cardiac CT is the lack of ionizing radiation or potentially harmful iodinated contrast.

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