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Cardiothoracic Imaging · Point/Counterpoint

Cardiac MRI Protocols: Point–A Complex Organ With Complex Disease Should Be Studied Using Comprehensive Protocols

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Please see the corresponding Counterpoint by Allen in this issue:
Cardiac MRI Protocols: Counterpoint—Focused Cardiac MRI Is Optimal for Patients, Imagers, and Practices.

Cardiac pathologies are highly complex, presenting with overlapping features and sometimes occurring coincidentally. For example, myocardial hypertrophy can arise from such varied factors as sarcomere gene mutations, aortic valve disease, hypertension, and a number of storage diseases. Thus, when performing cardiac MRI, the complexity of the potential underlying pathology necessitates use of comprehensive protocols to identify not only structural changes but also associated alterations in cardiac volumes and kinetics, to narrow differential diagnoses. In adults, cardiac pathologies can coexist with ischemic heart disease due to coronary atherosclerosis, which occurs among individuals in a similar age range. Indeed, one of the most common and well-established indications for cardiac MRI is newly diagnosed cardiomyopathy, for which the examination seeks to differentiate the diagnosis from potentially overlapping conditions and help establish the etiology.

Most sequences within modern cardiac MRI protocols are standardized and optimized for short acquisitions, lending themselves to a protocol that allows technologists to efficiently progress through examinations while requiring relatively few inputs. In contrast, an approach of crafting a tailored examination for each patient can lead to errors and unintentional omissions. In most settings, MRI is performed late during disease workup, often after multiple prior examinations have been performed, such as echocardiography, cardiac CT, nuclear imaging, and even invasive coronary angiography. The expectation of the MRI examination is thus to provide the most decisive result possible as a final or near-final diagnostic step. Accordingly, a standardized and comprehensive protocol is ideal for most cardiac MRI examinations today.

All cardiac MRI examinations begin with proper localization and creation of the standard cardiac imaging planes, including two-chamber, four-chamber, three-chamber, and short-axis views of the left ventricle. The workhorse sequence for functional evaluation is the SSFP cine sequence, a bright-blood sequence with mixed T2/T1 weighting that provides a high SNR, resulting in excellent contrast between the blood pool and surrounding tissue [1]. Standard coverage in patients with inherited pathogenic or likely pathogenic gene mutations associated with arrhythmogenic right ventricular cardiomyopathy (i.e. *PKP2*, *DSP*, *PLN*) should include the right ventricle and right ventricular outflow tract [2]. In the workup of constrictive pericarditis, real-time free-breathing cine images visualize ventricular interdependence via respiratory septal shift during inspiration.

T1-weighted black-blood images can more optimally identify myocardial free fatty deposition, which shows low signal with the use of fat suppression versus high signal without its use. Congenital cardiac and vascular anomalies are well visualized with advanced accelerated 3D noncontrast MR angiography techniques. Shunts can be quantified via 2D velocity-encoded phase-contrast imaging, which is typically acquired perpendicular to the ascending aorta and pulmonary artery, to calculate the Qp/Qs ratio (i.e., the ratio of pulmonary blood flow to systemic blood flow). In more complex situations, contemporary 4D phase contrast sequences allow a standardized volume acquisition with creation of unlimited dedicated planes during postprocessing (in contrast with the approach of acquiring numerous separate 2D double-oblique acquisitions).

Myocardial fibrosis is classified as either replacement or interstitial fibrosis [3]. Replacement fibrosis results from myocyte necrosis and scarring primarily due to the accumulation of type 1 collagen. Interstitial fibrosis is a reactive and more common condition that is associated with factors including aging, hypertension, dilated cardiomyopathy, and infiltrative disease (a less common entity linked to deposition of insoluble proteins in amyloidosis or of glycosphingolipids in Fabry disease). Late gadolinium enhancement (LGE) imaging is the standard technique for detecting focal myocardial fibrosis, which shows hyperintense signal due to gadolinium accumulation in the expanded extracellular space. LGE imaging is optimized by use of an inversion recovery sequence to null signal from healthy myocardium. In particular, use of modern phase-sensitive inversion-recovery sequences for LGE imaging allows higher scar-to-blood contrast. LGE imaging can differentiate ischemic from nonischemic cardiomyopathy by assessing the location and extent of scar tissue. Distinct LGE patterns are linked to specific types of nonischemic cardiomyopathies. Early gadolinium enhancement imaging, performed 1–3 minutes after contrast medium injection, or first-pass perfusion imaging, can identify areas of microvascular obstruction or visualize highly vascularized cardiac tumors such as angiosarcoma.

LGE imaging cannot detect diffuse interstitial myocardial fibrosis. Rather, T1 and extracellular volume (ECV) mapping techniques (the latter calculated from precontrast and postcontrast T1 times and hematocrit values) are essential tools to identify diffuse myocardial fibrosis. Systemic conditions such as amyloidosis, lupus, or

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systemic sclerosis may be associated with widespread prolongations in T1 times (typically to > 1100 ms at 1.5 T, with an additional increase of 14–28% at 3 T) [4] and a subsequent increase in ECVs (generally by > 29%) [5]. Elevated T1 and ECV values may also be observed in conditions including dilated or hypertrophic cardiomyopathy and correlate with reduced and increased wall thickness, respectively [6]. T2-weighted STIR and T2 mapping detect edema in pathologies such as acute myocarditis that show, in addition to elevated T1 and ECV values, prolonged T2 times (i.e., ≥ 60 ms) [7]. Iron overload due to siderotic cardiomyopathy (e.g., hemochromatosis) is measured via T2* imaging.

In patients with ischemic heart disease, ischemic reserve is assessed via stress first-pass gadolinium perfusion imaging performed in the presence of a vasodilatory agent (e.g., adenosine, regadenoson). Subendocardial territories in a stenotic coronary distribution with reduced blood flow will appear hypointense during the first pass when this technique is used. Rest perfusion images can be performed for comparison, to increase sensitivity.

A standard comprehensive cardiac MRI protocol for nonischemic cardiomyopathy (a complex and varied set of diagnoses) should include rest cine imaging, native T1 mapping, and LGE imaging as well as postcontrast T1 and ECV mapping. T2 imaging is also helpful in the setting of active or acute disease. A comprehensive protocol for ischemic cardiomyopathy should include stress perfusion, rest perfusion, cine, and LGE imaging; T1 and ECV mapping may also be helpful for patients with acute myocardial infarction. Additional phase-contrast imaging and 3D MRA may be added to either protocol.

The role of cardiac MRI is frequently that of a final arbiter after prior noninvasive diagnostic testing, and most sequences can be efficiently applied for evaluation of a wide range of pathologies. Comprehensive standardized protocols address a broad range of commonly encountered, and sometimes overlapping, pathologies.

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