Patterns of late myocardial enhancement in cardiac MRI

Poster No.: C-0683
Congress: ECR 2010
Type: Educational Exhibit
Topic: Cardiac
Authors: A. F. L. Carneiro, A. S. R. Preto, R. C. Ramos, A. J. B. S. Madureira; Porto/PT
Keywords: Cardiac MRI, Late Enhancement, Cardiomyopathies
DOI: 10.1594/ecr2010/C-0683

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method is strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Learning objectives

We aim to depict the distinct patterns of late myocardial enhancement in contrast enhanced MRI and how they relate to different disease entities. We also intend to explain how and why late enhancement works.

Background

Introduction

For the last 15 years, late contrast enhancement has been used to characterize myocardial tissue properties and diagnose several different disease entities.

It has been known for a long time that myocardial necrosis exhibits higher signal intensity in T1-weighted MR image, after administration of contrast agents, particularly gadolinium. In this setting, expanded extracellular volume, abnormal wash-in and washout, results in a larger distribution volume, earlier uptake and slower return to the blood pool for the contrast agent. In necrosis, expanded extracellular volume is function not only of cell death, but also acute inflammation and the edema that ensue.

In clinical practice, myocardial necrosis is most frequently found after sustained (>20 minutes) cardiac ischemia. Thus, a large number of cardiac MRs are performed after coronary events, to study functional status, wall motion abnormalities, infarct area and myocardial viability.

Nonetheless, myocardial necrosis also occurs in other settings, producing late enhancement, albeit in different patterns.

Conversely, other disease entities can also be responsible for changes in the extracellular volume or the wash-in/wash-out properties of myocardium. Fibrosis is the more important of these and is, not incidentally, the main pathological correlate of late enhancement in chronic ischemia.

For the cardiac radiologist, it is fortunate that ischemia tends to occur in definite patterns, which are fundamentally opposed to those of other disease entities, allowing for differential diagnosis. It's no less important that the imaging so closely reflects the events at cellular and physiological level, allowing for easier understanding.
**Delayed enhancement contrast MRI**

Several studies have shown that infarcted myocardium is best visualized after injection of paramagnetic contrast agents, using Gradient-Echo acquisitions following a 180° Inversion Recovery pre-pulse (contrast-enhanced inversion recovery MRI).

In these sequences, the IR pulse is not used to suppress the signal of fat as is in STIR sequences. Instead signal from normal myocardial tissue is annulled. The inversion time for this sequence is variable and dependent on factors such as patient weight, contrast dose, renal function, and timepoint after injection. After the inversion pulse, tissues recover magnetization. When normal myocardium signal crosses the zero line, tissue signal should be acquired.

Normal myocardium should appear as dark, contrasting with abnormal tissue in which gadolinium is still present and that shows high signal.

Because the inversion time in these sequences is used for myocardial suppression, if additional suppression of fat is desired, another technique must be employed, namely spectral fat-suppression.

The role of the IR prepulse is to increase T1 weighting, which results in improved contrast between enhanced and nonenhanced tissues. The greatest differences in regional myocardial MR signal intensity are obtained with a segmented kappa-space GRE pulse sequence with an inversion time set to null normal myocardial signal intensity after contrast-material administration.

Typically, heart images are acquired at 8-30 min after administration of the contrast agent. In myocardium with increased extravascular space or abnormal contrast wash-in-and washout characteristics, gadolinium is withheld in the third space for a longer period and increases relaxation of adjacent water molecules, which are responsible for the higher signal. In normal tissue washout of gadolinium will have occurred before this time period and signal will be lower.

Ideally, one should acquire images at a time when enough contrast has cleared out of the blood that the signal intensity of blood is an intermediate gray.
Fig.: Fig 1. This graphic illustrates the time varying effects of gadolinium on healthy and ischemic myocardium.

References: Department of Radiology, Gasthuisberg, Leuven, Belgium 2009

3D sequences are preferred as they have the ability to cover the entire ventricle in a single breath-hold period, even though the echo train length can be quite long in patients with higher heart rates. Long acquisition durations lead to blurring due to motion superposition and T2-dephasing effects.

Late enhancement kynetics

When injected intravenously, gadolinium-based contrast agents are delivered to tissues in the body proportionally to their perfusion.

These contrast agents rapidly diffuse into the extracellular space but, because of chemical charge and molecular size, they cannot cross intact cell membranes.
After a bolus injection of gadolinium, perfusion significantly modulates arrival and clearance of contrast in normal and infarcted myocardium.

Ex vivo experiments indicate that delayed enhancement is not caused by gadolinium binding to the infarcted myocardium. Although normal myocardium enhances to some degree with these contrast agents, infarcted myocardium accumulates much more contrast than normal myocardium. This is what is termed delayed enhancement.

This term originated from early studies that showed low signal intensity in the infarct shortly after injection, followed several minutes later, by intense enhancement.

Gadolinium accumulates in the myocardium with similar spatial distribution as sodium ion, and its myocardial concentration is inversely related to that of potassium.

In normal myocardium, cell membranes pump sodium out of the cell and maintain high potassium concentration within the cell. In acutely infarcted myocardium, loss of cell membrane integrity allows sodium and gadolinium into the intracellular space. In chronic infarcts, the gadolinium also tracks with sodium. In chronic infarcts, which have large areas of collagen scar and relatively limited intracellular space, the high gadolinium concentration represents the abnormally large extracellular space. Thus, the myocardial distribution of gadolinium provides information about the integrity of cell membranes and therefore viability.

Current extracellular gadolinium-based contrast agents differentiate acute myocardial infarction from normal myocardium based on the relative volume of distribution of contrast. In viable myocardium, intact cell membranes effectively exclude the extracellular gadolinium contrast agents from the intracellular space.
**Fig.**: Fig 2. The volume of distribution of Gadolinium in healthy cardiac tissue (above) is smaller and mainly limited to the extracellular space. With ischemia or other insults (below) the extracellular space increases, as does the permeability of cells to Gadolinium. Thus, the volume of distribution for gadolinium is larger and it is washed out over a longer period.

**References**: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Thus, gadolinium concentration tracks sodium and is inversely related to tissue potassium distribution. In acute myocardial infarction, the necrotic or dying cardiomyocytes lose cell membrane integrity, and extracellular gadolinium contrast agents can enter cells. This results in higher contrast concentrations in the area of acute myocardial infarction and consequently bright signal intensity in the infarct zone in delayed enhancement imaging.

Chronic myocardial infarction also enhances, but for slightly different reasons. Fibrous scar or collagen scar is a relatively acellular tissue with a small number of fibroblasts and a small intracellular volume. Because the intracellular space of collagen scar is relatively small compared to the extracellular space, this tissue enhances substantially more than normal myocardium. Thus, both acute and chronic myocardial infarctions typically appear bright on delayed enhancement images.
Fig.: Fig 3. In chronic infarcts or after prolonged injury, cardiomiocytes are replaced by fibrotic tissue (collagen and fibroblasts). In fibrosis, the volume of distribution for Gadolinium is larger than that of healthy muscle.

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

The presence of hyperenhancement on postcontrast T1 weighted images merely suggests that the normal fluid homeostasis within the heart has been altered due to rupture of cell membranes or ultrastructural changes in myocyte organization. Many studies describe the very same changes in myocarditis, infiltrative cardiomyopathy, pericardial inflammation, hypertrophic cardiomyopathy, and cardiac masses. As can be expected cell death, extracellular volume expansion and fibrosis are the endpoints of many pathological pathways and are found in all these diseases to a larger or smaller extent. Differential diagnosis is based on the results of other tests, in the location and pattern of late enhancement and in also other MRI findings, such as heart size, structure and function.
The quality of the superior spatial resolution obtained with current MRI is underlined by several studies that favorably compare its ability to detect and quantify subendocardial scarring to nuclear medicine techniques. MRI might replace PET as the standard of reference in the assessment of myocardial viability.

Other studies in myocardial infarction which have focused on T2-weighted MRI have suggested that, although T2-weighted MRI may be able to detect the presence of myocardial damage, the areas that exhibit increased signal intensity are probably related to the presence of myocardial edema, rather than the myocardial infarction, especially in the acute phase.

T2-weighted images overestimate the size of the infarct area and correlate well with the dysfunctional myocardial region. It's generally regarded that this area represents stunned but viable myocardium, in which recovery can be gained.

**Fig.** Fig 4. The two top images are T2-weighted acquisitions with FS, the bottoms ones being delayed enhancement imaging (3D SCAR, 1.5T, Philips). In acute infarct transmural edema is apparent in the T2 image. Transmural enhancement is also found.
In the chronic setting T2 images do not show edema. Areas of moderate wall thinning are apparent. Delayed enhancement is also positive (arrows, right bottom image), although for different reasons (fibrosis).

**References:** Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

**Images for this section:**

![Contrast-Enhanced MRI Time-varying effects](image)

**Fig. 1:** Fig 1. This graphic illustrates the time varying effects of gadolinium on healthy and ischemic myocardium.
**Fig. 2:** Fig 2. The volume of distribution of Gadolinium in healthy cardiac tissue (above) is smaller and mainly limited to the extracellular space. With ischemia or other insults (below) the extracellular space increases, as does the permeability of cells to Gadolinium. Thus, the volume of distribution for gadolinium is larger and it is washed out over a longer period.
Fig. 3: In chronic infarcts or after prolonged injury, cardiomiocytes are replaced by fibrotic tissue (collagen and fibroblasts). In fibrosis, the volume of distribution for Gadolinium is larger than that of healthy muscle.
**Fig. 4:** The two top images are T2-weighted acquisitions with FS, the bottoms ones being delayed enhancement imaging (3D SCAR, 1.5T, Philips). In acute infarct transmural edema is apparent in the T2 image. Transmural enhancement is also found. In the chronic setting T2 images do not show edema. Areas of moderate wall thinning are apparent. Delayed enhancement is also positive (arrows, right bottom image), although for different reasons (fibrosis).
Imaging findings OR Procedure details

Imaging findings: Myocardial infarction

The use of gadolinium based contrast agents in conjunction with CE-IR MRI has been firmly established as a valuable tool to visualize, in detail, the presence of myocardial infarction. This is mainly due to the differential effect of the contrast agent on relaxation times of normal and infarcted myocardium and due to the high contrast ratio of the sequences employed.

Immediately after contrast administration, there is a brief enhancement of the normal myocardium. Due to the rapid washout of contrast from normal myocardium, its enhancement decays substantially at 5 min post contrast. An opposite phenomenon is observed in infarcted myocardium. At 5 min, contrast persists in extra-cellular space, making T1-relaxation time significantly shorter. The infarct area is thus bright relative to the viable myocardium. Somewhere between 5 (or 8 or 10 minutes, according to the different authors) and 30 min after contrast administration, T1-relaxation of the infarcted or scarred myocardium is optimal for imaging with CE-IR MRI.
Fig.: Fig 1. Delayed enhancement imaging (3D SCAR, 1.5T, Philips) showing findings at different timepoints in short axis view. At 25 minutes an extensive inferior transmural infarct becomes most conspicuous. It spreads out to the septal and infero-lateral walls. This patient had a history of documented CAD as well.

References: Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

At 30 min, as contrast washout progressively takes place, in the infarcted myocardium, T1-relaxation times again increase, blurring the distinction between healthy and diseased tissue.

Four different patterns of infarct enhancement, reflecting the depth or severity of AMI, have been described.

These patterns reflect, to a degree, the events at cellular level during myocardial infarction. During coronary artery occlusion, the area of ischemia and cell death spreads
transmurally over time, like a wave front, from the endocardium towards the epicardium. These events are a function of regional flow and oxygen consumption, which are more critically balanced in the endocardium.

This sequence of involvement and the associated enhancement patterns are proportionately to peak creatine kinase levels, regional functional parameters, and are prognostically important.

The analysis of the degree of transmurality of enhancement on a segmental or regional basis is a critical determinant of recovery of contractile function in the postinfarction period or, in other words, myocardial viability.

The first pattern of delayed MR hyperenhancement is that of subendocardial late-enhancement alone, with sparing of the subepicardial layer. This subendocardial enhancement is related to less extensive, often non-Q-wave, infarcts that are known to have a better patient outcome. It is important to realize in this setting that, at present, delayed hyperenhancement is virtually the only imaging technique that is able to demonstrate these subendocardial infarctions with sufficient spatial resolution.
Fig.: Fig 2. Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis (top) and vertical long-axis views (bottom). There is a small focal spot of subendocardial enhancement (arrow) in the anterior left ventricle wall of this patient with a history of CAD.

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Fig.: Fig 3. Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis (left) and horizontal long-axis (right) views. There is a large patch of subendocardial enhancement in the lateral and infero-lateral wall of the left ventricle of this patient who had an unclear medical history. These findings are highly suggestive of CAD.

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Delayed-enhancement MRI depicts nontransmural hyperintensity in all subjects with clinical evidence of non-Q-wave infarcts.

The second pattern consists of delayed hyperenhancement extending over the full thickness of the myocardial wall, representing complete transmural but reperfused infarcts. Usually this pattern is seen in larger infarcts, and the likelihood of functional recovery of these infarcts after revascularization is very small.

The third pattern is similar to the enhancement seen in transmural infarcts, but is distinguished by the appearance of a subendocardially located hypointense area. This area is best seen on delayed-enhancement images taken early after injection, since in this phase, the contrast between this dark area and the transient myocardial enhancement, in both normal and injured myocardium, is greatest. This pattern represents transmural infarctions in which the reperfusion was only partially successful with residual lack of reperfusion at the tissue level, i.e., the no-reflow phenomenon. The area of no-reflow is associated with severe edema compressing intramural vessels or extensive myocardial necrosis and microcirculatory damage in the center of a large infarction.
It has been reported that the area of no-reflow is a better predictor of LV dilatation than the infarct size. It has also been reported that no-reflow zones have no inotropic reserve, which directly related to the transmurality of enhancement (and thus necrosis).

A fourth pattern is seen in nonreperfused, occlusive, infarcts. These infarcts are visualized as peripheral enhancement surrounding a dark core of non-perfused myocardium. Patterns three and four reflect extensive myocardial infarction with infarct expansion, less viable myocardium, more nonischemic dysfunction, and worse outcome.

Fig.: Fig 4. Delayed enhancement imaging (3D SCAR, 1.5T, Philips), short axis view, illustrating the 4 different pattern that can be found in ischemic disease (see text).

References: Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image.

Regardless of the location of a myocardial infarction, the pattern of enhancement always presents as spreading outward from the endocardium. Whether the infarction itself is
subendocardial or transmural, the subendocardium is always involved. Furthermore, the infarct location always can be traced back to a certain "culprit" artery, which is to say, although the supply territories of the three major coronary arteries are variable depending on coronary artery anatomy, the infarction is always located within the anatomical territory supplied by one or more coronary arteries, and the intensity of abnormalities increases toward the myocardium that is terminally perfused by that coronary artery.

The morphology of an area of delayed enhancement in myocardial infarction is also relative to the longitudinal distribution of the blood supply of the coronary artery.

In inferior infarctions, the area of enhancement is more pronounced in the basal and mid-ventricular myocardium, whereas lateral wall infarctions are more oriented toward the mid-ventricular and apical portions.

Anterior infarctions are usually very large and spread out from the anterobasal wall and may include the apex. Inferior infarctions may extend toward the inferolateral right ventricular (RV) wall, while isolated RV infarctions seldom occur.
Fig.: Fig 5. The image on the top left illustrates a frame from a cine steady-state acquisition. A large apical aneurysm is apparent in this patient, who had had an extensive infarct one year previous. The top right and bottom images are delayed enhancement images (SPIR, 3T, Siemens). They show thinning and exuberant enhancement of the wall of the aneurysm. No thrombus was found.

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Imaging findings: Myocarditis

Myocarditis is defined as an inflammatory infiltrate of the myocardium with necrosis or degeneration of adjacent myocytes, in the absence of the typical of ischemic damage associated with coronary artery disease. Although the etiology is often unknown (i.e.
idiopathic), myocarditis can be found in a variety of diseases affecting the myocardium and/or other parts of the heart. Though virtually any infectious agent may cause myocarditis, most cases of acute myocarditis are caused by viruses (e.g. coxsackie B4 virus, adenovirus, human immunodeficiency virus, etc).

Myocarditis may also be caused by allergic reactions and pharmacological agents, as well as during the course of some systemic diseases such as vasculitis.

The clinical features of myocarditis are varied, making the diagnosis of myocarditis often difficult at initial presentation.

Most cases of myocarditis are insidious and have an asymptomatic course. Post-mortem studies, however, suggest that myocarditis is a major cause of sudden, unexpected death in adults less than 40 years of age.

Patients may present with a history of a recent, flulike syndrome, accompanied by fever, arthralgia and malaise. Cardiac symptoms range from mild clinical cardiac failure and ventricular dilatation to fulminant cardiac failure and severe LV dysfunction with or without cardiac dilatation. Although the clinical course is usually benign with spontaneous recovery, sudden death may occasionally occur, and 5-10% of patients may progress to develop chronic DCM.

Endomyocardial biopsy specimens are considered diagnostic of active myocarditis if routine light microscopy reveals infiltrating lymphocytes and myocytolysis. However, using the "Dallas" criteria, only 10- 25% of patients in whom myocarditis is suspected on clinical grounds have positive biopsies. This suggests that endomyocardial biopsy underestimate the true incidence of myocarditis. Thus, endomyocardial biopsy has a poor negative predictive value of active myocarditis, but a high positive predictive value.

Use of MRI in the diagnosis of myocarditis was reported in the early 1990s

The lymphocyte infiltrate and myocytolysis in patients with active myocarditis increases the myocardial free-water content. As a result, the proton relaxation time, especially the T2-relaxation time, is prolonged and the diseased myocardium is visible as a hyperintense area on T2- weighted MRI sequences.

Administration of gadolinium-based paramagnetic contrast agents is helpful in identifying the exact region of myocardial damage due to myocarditis, and to monitor the myocarditis activity.

Increased distribution volume due to acute cell damage, with diffusion of gadolinium into the intracellular space, is the most likely mechanism to explain the enhancement in the
pathological areas. In addition, a similar enhancement is shown in the pericardium if this part of the heart is involved in the inflammatory process.

In patients with evidence of ongoing disease, a persistent enhancement is found. Contrast enhancement at 4 weeks after the onset of symptoms is shown to be predictive of a worse functional and clinical long-term outcome.

Delayed enhancement may be found in up to 88% of patients. The lateral LV wall is most frequently involved, and the foci of enhancement were typically located in the outer myocardial layers, sparing the subendocardium (in contrast to the enhancement pattern found in patients with acute myocardial infarction.) The information on the exact localization of myocardial damage caused by the myocarditis on the CE-IR MRI can be used to guide biopsy.

Moreover, cine MRI techniques, especially the new steady state techniques, allow accurate assessment of the impact of the myocardial damage on regional and global ventricular function in patients with active myocarditis.

![Myocarditis](image)

PBV 19
Good prognosis

HHV 6
Poor prognosis
Fig.: Fig 6. Delayed enhancement imaging (3D SCAR, 1.5T, Philips), horizontal long axis views, illustrating 2 different patterns of wall involvement in myocarditis. In the left image an endomyocardial stripe can be seen in the mid to basal septal wall. Parvovirus was found in serological testing. In the right image a subepicardial mid to basal lateral wall patch was apparent. Antibody tests proved positive for recent Herpes 6 infection. 

References: Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

![Image of myocarditis pattern](image1)

Fig.: Fig 7. Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis view. There is subepicardial enhancement in the mid inferior wall of the left ventricle of this patient who presented with typical symptoms of myocarditis and troponin elevation. 

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

**Imaging Findings: Sarcoidosis**

Sarcoidosis is a multisystem granulomatous disorder of unknown etiology. The disease affects the hilar lymph nodes and the lungs most commonly.

Sarcoid myocardial involvement is present at autopsy in 20-30% of patients. The pathological features of cardiac sarcoidosis include patchy infiltration of the myocardium with three successive histological stages: edema, non-caseating epitheloid granulomatous infiltration, and fibrosis leading to postinflammatory scarring.
The clinical manifestations depend on the location and extent of granulomatous inflammation. Findings range from benign arrhythmias, heart block, intractable heart failure, intense chest pain and congestive heart failure to fatal ventricular fibrillation. Only 5% of patients with cardiac sarcoidosis are symptomatic. Though most patients experience a subclinical, asymptomatic course of the disease, there is a clear increased risk of sudden cardiac death, due to ventricular arrhythmias or conduction block, accounting for 30-65% of fatalities.

Cardiac involvement may proceed, follow or occur simultaneously with the involvement of the lungs or other organs. Early diagnosis and effective treatment in patients at risk are absolutely necessary to improve the long-term prognosis. The diagnosis of myocardial sarcoidosis is difficult and frustrating.

Because of the focal myocardial involvement of cardiac sarcoidosis, endomyocardial biopsy yields low sensitivity values.

Three different MRI patterns of myocardial involvement have been described: (1) the pure nodular pattern with a peripheral increased and a central decreased intramyocardial signal intensity on both T2-weighted and gadolinium-enhanced T1-weighted images (representing hyaline fibrotic tissue); (2) the inflammatory focal or patchy pattern, with increased signal on gadolinium-enhanced T1-weighted images with or without myocardial thickening; and (3) the postinflammatory pattern with focal increased signal on T2-weighted images (but no gadolinium uptake) with or without myocardial thinning.
**Fig.**: Fig 8. Delayed enhancement imaging (3D SCAR, 1.5T, Philips), short axis views. An area of nodular thickening was found in the inferior wall of the left ventricle. It also enhanced intensely. The patient had multi-organ involvement by sarcoidosis.

**References:** Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

Enhancement of the anteroseptal and anterolateral LV wall following gadolinium administration is frequently found.

The location of the abnormalities on cardiac MRI may be useful to guide endomyocardial biopsy (to increase sensitivity). In addition, regional and global ventricular function can be simultaneously quantified and extracardiac signs of sarcoidosis, e.g. mediastinal and hilar adenopathy, can be imaged with MRI.

**Imaging Findings: Amyloidosis**
Amyloidosis frequently involves the heart and is a common cause of secondary RCM. Deposition of amyloid fibrils occurs in myocardial tissue, valve leaflets and myocardial vessels. The clinical presentation varies and may mimic other infiltrative cardiomyopathies or storage disorders, as well as HCM. Although the therapeutic means are limited and treatment is generally unsatisfactory, the diagnosis is important to exclude the potentially curable conditions that it may mimic.

Several findings have been described in cardiac amyloidosis. Although each finding alone is nonspecific, a combination of different findings makes the diagnosis of cardiac amyloidosis likely, especially in conjunction with a positive extramyocardial biopsy.

Morphologically, the infiltration by amyloid protein results in a homogeneously increased thickness of ventricular and atrial walls. The ventricular cavities have a normal or reduced size. A severe concentric hypertrophy of both normal-sized ventricles in the absence of arterial hypertension or valvular heart disease is suggestive of amyloidosis. The increase in myocardial wall thickness in cardiac amyloidosis may mimic HCM. Asymmetric septal hypertrophy is found in 15-55% of cases of cardiac amyloidosis in combination with a systolic anterior motion of the mitral valve and early systolic closure of the aortic valve.

Other morphological findings include thickening of the papillary muscles and valve leaflets. The atria are usually enlarged owing to the diastolic dysfunction and/or valvular dysfunction due to amyloid deposition. Pleural and pericardial effusions may be seen.

The cardiac amyloid deposits generally cause severe cardiac dysfunction with a poor prognosis. It is generally considered that congestive heart failure is predominantly a diastolic phenomenon, with systolic dysfunction only occurring late in the disease. Therefore, severe congestive heart failure often occurs despite a normal or mildly reduced LV ejection fraction.

Inhomogeneously decreased signal intensity of the myocardium is found using SE-MRI in patients with cardiac amyloidosis, but not in patients with idiopathic RCM. A combination of a thickened atrial septum and right atrial free wall, and depressed contractility of a thickened myocardium with inhomogeneous reduction of the signal-intensity ratio is highly suggestive of cardiac amyloidosis.

At cardiac contrast MR imaging, cardiac amyloidosis frequently produces diffuse left ventricular subendocardial late enhancement.

Caution must be exercised when choosing the inversion time to null normal myocardial signal in cases of diffuse amyloidosis, since the infiltrative amyloid protein causes T1 prolongation. Given the frequently diffuse nature of cardiac amyloidosis, differentiating normal from abnormal myocardium during the selection of inversion time can be very
difficult. If the subendocardium is incorrectly presumed to be normal myocardium and its signal nulled, the reverse of the typically described enhancement pattern may be obtained.

**Fig.**: Fig 9. Delayed enhancement imaging (SPIR, 3T, Siemens) showing horizontal long-axis view. There is diffuse thickening of the walls of the cavities, including the atrial septum. Diffuse patchy enhancement is also found. The atria are involved. The image quality is low, the myocardium and the blood pool signals are low. These are common "problems" in patients with amyloidosis.

**References:** A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL
Absence of residual contrast agent within the blood pool on delayed postcontrast images has also frequently been described, presumably due to systemic retention of the gadolinium-based contrast agent in the extracellular spaces throughout the body in advanced cases of amyloidosis.
Fig.: Fig 11. Left image is a cine frame from a cine steady state sequence. On the right, we present a delayed enhancement image (3D SCAR, 1.5T, Philips). Both are horizontal long-axis view. In this other patient with amyloid, enhancement is even more intense. There are pleural and pericardial effusions.

References: Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

Imaging Findings: HCM

The characteristic finding of HCM is an inappropriate myocardial hypertrophy in the absence of an obvious cause for the hypertrophy, such as systemic hypertension or aortic stenosis. Familial clustering is often observed, and the disease is genetically transmitted in about half of the cases. The natural history and clinical presentation of HCM are variable. Symptoms are caused by intraventricular, usually LV outflow tract
(LVOT) obstruction, myocardial ischemia and reduced coronary vasodilator flow reserve, diastolic dysfunction and arrhythmias.

Although patients might be completely asymptomatic, HCM is the most common identified cause of sudden cardiac death in young people, due to arrhythmia. Histologically, HCM is characterized by a disorganization and malalignment of the myofibrils, i.e. myofibrillar disarray, which is not unique to HCM but is clearly more extensive in this disorder than in secondary myocardial hypertrophy from pressure overload or congenital heart disorders. The combination of inappropriate myocardial hypertrophy, intimal hyperplasia of intramural coronary arteries and endothelial dysfunction causes myocardial ischemia and spontaneous myocardial infarction in the absence of abnormalities of epicardial coronary arteries.

HCM typically produces marked asymmetrical hypertrophy of the left ventricle. The end-diastolic LV wall thickness is typically greater than 15 mm.

In 70% of patients, the ventricular septum and anterior LV wall are involved. Abnormalities are usually most prominent in the basal segments (previously called "idiopathic hypertrophic subaortic stenosis" and "muscular subaortic stenosis". Less frequent locations of myocardial hypertrophy include: the mid-portion of the ventricular septum, the apex, and the lower portion of the septum. Severe concentric hypertrophy may occur and papillary muscles and RV may also be hypertrophied. Secondary, left atrial enlargement is usually found.

Approximately 25% of patients with HCM have a dynamic outflow tract obstruction caused by a narrowed LVOT and abnormal systolic anterior motion of the mitral valve.

MRI allows the use of angled planes, with accurate measurement of the myocardial wall thickness.

Using cine MRI sequences, obstructive forms can be differentiated from non-obstructive forms of septal HCM. Flow acceleration and turbulence in the narrowed LVOT causes a dispersion of spin magnetization, generating a signal void in the LVOT during systole.

The global functional values in HCM are often increased with high ejection fractions and low end-systolic values. During cardiac contraction, incomplete compression of the ventricular cavities may occur in patients with severe HCM. In the thickened myocardial regions, however, systolic wall thickening is markedly reduced, which is related to muscle disorganization.
After gadolinium administration, the hypertrophic myocardium in patients with HCM shows a higher signal intensity ratio than non-hypertrophic regions and than myocardium in normal subjects, and a delayed decay of the signal intensity is present.

It has been hypothesized that the areas of abnormally high signal intensity in LV myocardium reflect myocardial ischemia and fibrosis due to small-vessel disease, or myocardial degeneration and necrosis.

Abnormal late enhancement is found in the majority of HCM patients, (around 80%). Enhancement was invariably found in the hypertrophied regions. The pattern of enhancement is usually patchy with multiple foci, predominantly involving the middle third of the ventricular wall. The junction of the ventricular septum and RV free wall is the most frequently involved area of enhancement.

The extent of enhancement is positively correlated with the wall thickness, and inversely with systolic wall thickening in the hypertrophied region.
**Fig.:** Fig 12. The two top images and the on the bottom right are cine frames from steady state sequences. They illustrate different forms of hypertrophy. An area of spin dephasing (arrow) is apparent in the top right image, suggesting the presence of sub-aortic stenosis. The bottom left images is from delayed enhancement imaging (3D SCAR, 1.5T, Philips). It shows enhancement in an area of hypertrophy: the basal lateral wall. The apex also enhances.

**References:** Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

It is generally believed that enhanced regions represent scarred myocardium or are in relation to myocardial disarray and consequent local interstitial expansion.

The pattern of enhancement corresponds to the typical pattern of myocardial scarring found in necropsy studies. Patients with diffuse enhancement have a higher risk of sudden cardiac death than patients with confluent enhancement. It is likely that the degree of diastolic dysfunction is linked to the extent of myocardial fibrosis, quantified by means of CE-IR MRI.

**Imaging Findings: Dilated Cardiomyopathy**

DCM is a syndrome characterized by LV or biventricular enlargement, cardiac hypertrophy and severely depressed systolic function.

At the cellular level, a combination of atrophy and hypertrophy of the myocytes is demonstrated. The myocardial hypertrophy consists of myocyte elongation with an in-series addition of newly formed sarcomeres, which is the major factor responsible for the increase in chamber size. The myocyte diameter also increases, although the lateral expansion of myocytes is modest and inadequate to preserve the ratio of the wall thickness to the chamber diameter at normal values. The structural correlate in the extracellular matrix is myocardial fibrosis with an excessive deposition of collagen in the ventricular wall. Myocardial fibrosis can be divided into three groups: mild diffuse fibrosis, severe diffuse fibrosis, and segmental fibrosis. The combination of ventricular dilatation and an inadequate increase in myocardial wall thickness leads to a decompensated eccentric hypertrophy and a consequent increase in ventricular wall stress.

Although the cause of DCM is often not definable (idiopathic DCM), a variety of cytotoxic, metabolic, immunological, familial and infectious mechanisms can produce the clinical manifestations of DCM. It is likely that DCM represents the final common pathway that is
the end result of myocardial damage. The clinical presentation of DCM is variable. The most common symptom is left-sided heart failure.

Cardiac imaging techniques are used to evaluate the size of the ventricular cavity and the thickness of the ventricular walls, to exclude concomitant valvular and pericardial disease, and to detect the repercussion of the LV dilatation on valvular function.

Use of gadolinium-enhanced MRI characterizes the myocardium and helps to differentiate DCM patients from LV dysfunction related to CAD.

No hyperenhancement is the most common pattern found in patients with non-ischemic cardiomyopathy, in contrast to the frequent hyperenhancement in patients with healed myocardial infarction.

**Fig.**: Fig 13. Cine frame from steady state sequence vertical long-axis (left) and horizontal long axis delayed enhancement imaging (3D SCAR, 1.5T, Philips-right image), showing an enlarged ventricle, with thinned walls. A thrombus was found in
the luminal apex. The apex enhances. This is not pure DCM, but instead it represents CAD-related ventricular dysfunction.

**References:** Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

Three different patterns in patients with DCM have been reported: (a) no enhancement (59%); (b) myocardial enhancement (i.e. subendocardial or transmural) indistinguishable from patients with CAD (13%); or (c) patchy or longitudinal striae of mid-wall enhancement clearly different from the distribution in patients with CAD (28%).

A significant number of DCM patients have normal luminal appearances by coronary angiography, but the pattern of subendocardial to transmural enhancement strongly suggests the presence of prior infarction. It is most likely that the normal coronary angiography findings can be explained by recanalization after an occlusive coronary event or embolization from minimally stenotic but unstable plaques. Therefore, these patients should be considered as having LV dysfunction related to CAD, rather than DCM patients.

The mid-wall linear and patchy enhancement probably reflects focal segmental fibrosis,

**Imaging Findings: Post Surgery**

Predictably, in patients who have undergone surgery, fibrosis at the site of intervention is a common finding. This represents a surgical scar, which is shown in delayed enhancement imaging. It shows as thinned high signal patch of myocardium, the size and location of which are determined by surgical procedure. Knowledge of medical and surgical history is of the greatest importance to prevent misdiagnosis.
**Fig.**: Fig 14. This patient with Tretalogy of Fallot had had a patch replacement of his right ventricular outflow tract (RVOT) (white arrow). Notice the thickening of the right ventricular free wall. Because pathological severe hypertrophy can be accompanied by fibrosis and cellular disarray, late enhancement (SPIR, Siemens 3T) was also apparent in that location (blue arrows).

**References:** A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Complications of surgery or intervention can also be detected.
Fig.: Fig 15. This patient had been submitted to mitral valve replacement one year before. He was doing well and was asymptomatic. Routine echocardiogram revealed a pseudo-aneurysm with was later confirmed and characterized by MRI. It was located in the basal lateral wall, immediately after the annulus of the the valve. Its origin is presumably iatrogenic. The stretched myocardium enhances brightly in delayed enhancement imaging (left and top right images). The bottom right image is a frame from a cine steady state sequence (True-FISP, Siemens 3T).

References: A. F. L. Carneiro; Radiology, Hospital São João, Porto, PORTUGAL

Imaging Findings: Cardiac Neoplasms

Cardiac tumors, whether primary of secondary can uptake gadolinium. T1 weighted sequences can better demonstrate early uptake, while delayed imaging is useful in less cellular lesions in which there is extracellular volume expansion. The pattern of uptake is not entirely predictable. Diagnosis must be based not only on contrast kinetic, but also on
the age of the patient, on the exact location of the lesion, other signal characteristics (i.e. T2w signal) and on whether there is a previous malignancy likely to metastize to the heart.

**Fig.**: Fig 16. A mass with 19mm was found in the atrial septum. This a common location for myxoma. This reflect its high water content. The lesion had uniformly bright signal on T2 images (top right). Contrast uptake was apparent in both early post-contrast T1w acquisitions (bottom left) and in the late enhancement sequences (bottom right).

**References**: Special thanks to Jan Bogart and Javier Ganame at Gasthuisberg, Leuven for this image

**Images for this section:**
Fig. 1: Delayed enhancement imaging (3D SCAR, 1.5T, Philips) showing findings at different timepoints in short axis view. At 25 minutes an extensive inferior transmural infarct becomes most conspicuous. It spreads out to the septal and infero-lateral walls. This patient had a history of documented CAD as well.
**Fig. 2:** Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis (top) and vertical long-axis views (bottom). There is a small focal spot of subendocardial enhancement (arrow) in the anterior left ventricle wall of this patient with a history of CAD.

**Fig. 3:** Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis (left) and horizontal long-axis (right) views. There is a large patch of subendocardial enhancement in the lateral and infero-lateral wall of the left ventricle of this patient who had an unclear medical history. These findings are highly suggestive of CAD.
Fig. 4: Delayed enhancement imaging (3D SCAR, 1.5T, Philips), short axis view, illustrating the 4 different pattern that can be found in ischemic disease (see text).
Fig. 5: The image on the top left illustrates a frame from a cine steady-state acquisition. A large apical aneurysm is apparent in this patient, who had had an extensive infarct one year previous. The top right and bottom images are delayed enhancement images (SPIR, 3T, Siemens). They show thinning and exuberant enhancement of the wall of the aneurysm. No thrombus was found.
**Fig. 6:** Delayed enhancement imaging (3D SCAR, 1.5T, Philips), horizontal long axis views, illustrating 2 different patterns of wall involvement in myocarditis. In the left image an endomyocardial stripe can be seen in the mid to basal septal wall. Parvovirus was found in serological testing. In the right image a subepicardial mid to basal lateral wall patch was apparent. Antibody tests proved positive for recent Herpes 6 infection.
**Fig. 7:** Fig 7. Delayed enhancement imaging (SPIR, 3T, Siemens) showing short-axis view. There is subepicardial enhancement in the mid inferior wall of the left ventricle of this patient who presented with typical symptoms of myocarditis and troponin elevation.
Fig. 8: Delayed enhancement imaging (3D SCAR, 1.5T, Philips), short axis views. An area of nodular thickening was found in the inferior wall of the left ventricle. It also enhanced intensely. The patient had multi-organ involvement by sarcoidosis.
Fig. 9: Fig 9. Delayed enhancement imaging (SPIR, 3T, Siemens) showing horizontal long-axis view. There is diffuse thickening of the walls of the cavities, including the atrial septum. Diffuse patchy enhancement is also found. The atria are involved. The image quality is low, the myocardium and the blood pool signals are low. These are common "problems" in patients with amyloidosis.
Fig. 10: Fig 10. Same patient as above.
**Fig. 11:** Left image is a cine frame from a cine steady state sequence. On the right, we present a delayed enhancement image (3D SCAR, 1.5T, Philips). Both are horizontal long-axis view. In this other patient with amyloid, enhancement is even more intense. There are pleural and pericardial effusions.
**Fig. 12:** Fig 12. The two top images and the on the bottom right are cine frames from steady state sequences. They illustrate different forms of hypertrophy. An area of spin dephasing (arrow) is apparent in the top right image, suggesting the presence of sub-aortic stenosis. The bottom left images is from delayed enhancement imaging (3D SCAR, 1.5T, Philips). It shows enhancement in an area of hypertrophy: the basal lateral wall. The apex also enhances.
**Fig. 13:** Fig 13. Cine frame from steady state sequence vertical long-axis (left) and horizontal long axis delayed enhancement imaging (3D SCAR, 1.5T, Philips-right image), showing an enlarged ventricle, with thinned walls. A thrombus was found in the luminal apex. The apex enhances. This is not pure DCM, but instead it represents CAD-related ventricular dysfunction.
Fig. 14: This patient with Tretalogy of Fallot had had a patch replacement of his right ventricular outflow tract (RVOT) (white arrow). Notice the thickening of the right ventricular free wall. Because pathological severe hypertrophy can be accompanied by fibrosis and cellular disarray, late enhancement (SPIR, Siemens 3T) was also apparent in that location (blue arrows).
Fig. 15: This patient had been submitted to mitral valve replacement one year before. He was doing well and was asymptomatic. Routine echocardiogram revealed a pseudo-aneurysm with was later confirmed and characterized by MRI. It was located in the basal lateral wall, immediately after the annulus of the the valve. Its origin is presumably iatrogenic. The stretched myocardium enhances brightly in delayed enhancement imaging (left and top right images). The bottom right image is a frame from a cine steady state sequence (True-FISP, Siemens 3T).
**Fig. 16:** A mass with 19mm was found in the atrial septum. This a common location for myxoma. This reflect its high water content. The lesion had uniformly bright signal on T2 images (top right). Contrast uptake was apparent in both early post-contrast T1w acquisitions (bottom left) and in the late enhancement sequences (bottom right).
Conclusion

Recognition of the different patterns of late enhancement with modern MRI is an important tool in the differentiation of a range of cardiac diseases. With knowledge of the correct clinical setting accurate diagnosis is possible.

Fig.: Summary of the patterns of late enhancement

References: Kwong R et al; Cardiovascular magnetic resonance imaging, Humana Press 2008

Images for this section:
Fig. 1: Summary of the patterns of late enhancement
Personal Information

References


-Kwong R et al; Cardiovascular magnetic resonance imaging, Humana Press 2008

-Bogaert J, Dymarkowski S, Taylor A; Clinical Cardiac MRI; Springer 2005

-Grizzard J, Judd R, Kim R; Cardiovascular MRI in Practice; Springer 2008

-Some of the images were kindly supplied by Jan Bogaert and Javier Ganame from Gasthuisberg, Leuven