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Foreword

Images are a central part of our lives. Of the five senses, the eyes and vision have indeed triumphed over the others. We live, think, and dream through images.

Television captures our imagination and sends messages to us through images to the extent that there are now news reports in total silence. Television sound is often just a background noise. Newspapers, even the daily ones, communicate to us through catchy and colourful images. Often leaders and politicians care more about their image than their mission.

It is, therefore, not surprising that image has also invaded medicine and cardiology in particular. When I was a student, I thought that to be a good cardiologist one should have very good hearing to capture all of the abnormal heart sounds. This is no longer the case. The image of the echocardiogram has surpassed the stethoscope; the eyes have surpassed the ears. Today, technology is providing heart doctors with more and more sophisticated and fascinating images. So, to be a good cardiologist, you have to read this book!

I mean it. As it always happens in life, interaction is important. This is also true for cardiovascular images that need to be integrated within themselves and particularly with the patients. Without such interaction and integration even the most sophisticated image will be dull.

Interaction is what this book is about. Several European leaders explain to the reader, in a simple and comprehensive manner, the value and the benefit of different imaging modalities in the diagnosis of the most relevant cardiovascular diseases.

This book does something more as well. It describes a new subspecialty that we will all soon need: the imaging doctor, who will be able to interact with clinicians and help them resolve diagnostic dilemmas by choosing the right technique and by interpreting images in a patient-based manner.

As the president of the ESC, I thank the ECHO Association, the working groups, and the councils who are responsible for *The European Society of Cardiology Textbook of Cardiovascular Imaging*.

As a cardiologist, I thank all the authors and editors for contributing to develop the education of all cardiologists (myself included) through this book.

President Roberto Ferrari
European Society of Cardiology

Introduction

MRI is a non-invasive imaging technique that permits the most complete study of aortic disease. It offers morphological, functional, and biochemical information. Technological advances, e.g. the implementation of faster gradients, newer sequences, and ultrafast MR angiography, have led to MRI being the modality of choice for imaging aortic diseases. Conventional ECG-gated spin-echo imaging and cine gradient-echo have earned MRI the reputation of being the ideal tool for evaluating the aorta. Contrast-enhanced 3D MR angiography permits rapid acquisition and multi-planar imaging with minimal dephasing artefacts. Phase-contrast imaging is another technique that enables flow in the great vessels to be evaluated with accurate quantification of peak velocity and forward and regurgitant flow.

MRI is increasingly becoming the first-line technique for evaluating diseases in the thoracic aorta.[1,2] MRI possesses the capability for multi-planar imaging; it uses a non-toxic contrast agent and does not involve ionizing radiation. With recent advances in gradient hardware, much shorter repetition times (TRs) are now achievable, resulting in significant increases in acquisition speed.

Magnetic Resonance Imaging Techniques

Black-Blood Sequences

Blood circulating through the aorta is black on conventional spin-echo and turbo spin-echo sequences owing to the emptying signal produced by the transit time effect of moving blood in the short phase. These sequences provide great morphological information on the aortic wall and adjacent structures. T1- or T2-weighted images are useful for characterization of wall tissue, permitting assessment of the haematic content of the intra-mural haematoma or the lipid content of the atherosclerosed plaque. Post-contrast T1 imaging with fat suppression is useful in the diagnosis of some entities such as aortitis or mycotic aneurysms. ECG triggering is essential in minimizing motion and pulsability artefacts. A slice of 3–8 mm and echo time (TE) of 20–30 msec are standard, while TR is determined from the R-R' interval of the ECG. ECG-triggered, breath-hold turbo-spin echo (TSE) has been the cornerstone of black-blood MRI for aortic disease. A double inversion-recovery technique is used to abolish the blood signal. The black-blood appearance is the result of nullifying the blood flowing into the slice by the first 180° inversion pulse at a specific inversion time (IT). Imaging occurs during mid to late diastole and the entire image is acquired over several heartbeats. Spin-echo single-shot (HASTE or SS-FSE) sequences permit correct morphological assessment of the aorta with very rapid acquisition times. Recently, a fast diffusion-prepared (DP) balanced SSFP-based magnetic resonance technique that allows for 3D dark blood imaging has been described. Since this is a 3D technique, the images offer improved slice resolution and more intuitive visualization of the thoracic aorta compared to 2D methods.

Cine-MR Sequences

Cine-MR images are acquired using gradient-echo sequences that provide excellent contrast between blood and surrounding tissue without the use of contrast agents. Contrast to noise depends on T2/T1 differences, which, with short TRs, are high for blood and low for tissues. Mainly due to their high temporal resolution, it is possible to obtain images of multiple phases of the heart cycle and visualize blood flow both in systole and diastole. Gradient-echo sequences generate images of brilliant blood. The emptying signal determines turbulent flow in haemodynamically significant stenosis or valvular regurgitation that may be useful in the detection of aortic coarctation or valvular disease. Steady-state free-precession sequences (True FISP, Fiesta or Balanced FFE) are those most commonly used. They are normally used for the functional study of cardiac chambers, although their use is widely extended to the study of the aorta. Their main characteristic is that they permit high-contrast images with very short acquisition times since they have very low TR.

Flow Mapping

Accurate quantitative information on blood flow is obtained from modified gradient-echo sequences with parameter reconstruction from the phase, rather than the amplitude of the MR signal; this is also known as flow-mapping or phase contrast or velocity-encoded cine MRI.

Velocity-encoded cine-MRI sequences provide great functional information owing to their capacity to quantify flow. Quantification of both flow velocity and volume permits physiopathological assessment of blood flow alterations in different aortic diseases. With this technique, the information is processed using signal magnitude images and phase images. Signal magnitude images are in brilliant blood and offer better anatomical assessment, while phase images show a map of flow velocities and direction. Using post-processing techniques, it is possible to obtain curves of flow vs. time, velocity vs. time, and peak velocity vs. time. Quantitative

Introduction

Cardiac CT allows non-invasive imaging of the coronary arteries. Under certain circumstances, it can, therefore, play an important role for diagnosing coronary artery disease. Particularly in patients with a relatively low pre-test likelihood of the disease, coronary CT angiography has been shown to allow for the detection of coronary stenoses with high sensitivity and is considered a useful technique to rule out coronary artery disease in selected clinical settings. Coronary artery imaging in patients with advanced disease or after coronary revascularization is more difficult and currently not considered a clinical indication for CT. In addition to detecting luminal stenosis, CT has the potential to visualize and characterize non-stenotic coronary atherosclerotic plaque. Based on a large amount of prognostic data, coronary calcium can be used for refined risk stratification concerning future cardiovascular events. Imaging of non-calcified plaque is currently considered experimental, and should not be used for clinical decision-making. Future improvements in image quality are expected to expand the clinical role of cardiac CT in the assessment of coronary artery disease.

The high temporal and spatial resolution of cardiac CT allows non-invasive visualization of the coronary arteries in selected patients and, therefore, makes the method very interesting for the non-invasive workup of patients with suspected coronary artery stenoses. However, spatial and temporal resolutions of CT imaging, even with the latest scanner generations, are not similar to invasive coronary angiography. Diagnostic accuracy is impaired when image quality is reduced, and image quality, in turn, is influenced by many factors such as the patient's heart rate, body weight, ability to cooperate, and extent of coronary calcification. Therefore, the clinical utility of coronary CT angiography significantly depends on the specific clinical situation, and thorough consideration of the advantages and disadvantages of CT angiography is necessary when deliberating the use of CT imaging in the workup of patients with known or suspected coronary artery disease.

In addition to the visualization of coronary artery stenoses, CT also allows the detection of coronary atherosclerotic plaque. In non-enhanced scans, coronary calcification is readily detectable, and in contrast-enhanced coronary CT angiography data sets of high-quality, coronary atherosclerotic plaques, including calcified and non-calcified components, can be visualized. There is tremendous interest in using this information for risk stratification concerning the occurrence of future coronary artery disease events.

This chapter will outline the potential applications of CT imaging for coronary artery visualization, detection of coronary artery stenoses, and risk stratification.

Coronary CT Angiography: Stenosis Detection

Imaging Protocols

For the assessment of symptomatic patients with chest pain, cardiac CT allows direct visualization of the coronary artery lumen ("coronary CT angiography"). As the small dimensions and the rapid motion of the coronary vessels pose tremendous challenges for non-invasive imaging, high-end CT equipment and adequate imaging protocols must be used. Currently, 64-slice CT is considered the "state of the art" for coronary artery imaging, and newer technology, such as Dual Source CT and scanners with 256 or 320 detectors, may provide further improved image quality.

Prerequisites for CT imaging of the coronary arteries include the ability to understand and follow breath-hold commands, because even slight respiratory motion during data acquisition will cause substantial artefact. Of further importance is a regular and, preferably, low heart rate (optimally below 60/min, even though this is not as strictly required for Dual Source CT).[1,2] Patients usually receive premedication with short-acting beta-blockers to lower heart rate, and nitrates are given to achieve coronary dilatation, which noticeably improves image quality. Iodine-based contrast agent is injected intravenously to achieve vascular enhancement during the scan. Typically, 50–100 mL of contrast agent is used. Data acquisition can follow various principles (see details in Chap. 5). *Retrospectively gated* scans are acquired in spiral mode and usually provide for higher image quality, more flexibility to choose the cardiac phase during which images are reconstructed, as well as the ability to reconstruct "functional" data sets throughout the cardiac cycle to assess wall motion. *Prospectively triggered* scans are associated with substantially lower radiation exposure and, especially in patients with truly low heart rates, are often adequate to assess the coronary lumen. Less flexibility to reconstruct data at different time instants in the cardiac cycle as well as greater susceptibility to artefacts caused by arrhythmia sometimes impair image quality so that there is a trade-off for the advantage of lower dose. Currently, the preferred strategy for coronary CT angiography has not been defined; however, in young patients in whom radiation dose may be of major concern, prospectively triggered scans should be strongly considered (also see Chap. 1e).

Typical data sets for coronary artery visualization by CT consist of approximately 200–300 transaxial slices with a thickness of 0.5–0.75 mm (see Fig. 13.1). Data interpretation is usually based on interactive manipulation of these data sets using post-processing workstations. Useful post-processing tools include maximum intensity projections and multi-planar