Imaging Pulmonary Arterial Thromboembolism

Challenges and Opportunities

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KEYWORDS

• Magnetic resonance angiography • Pulmonary arteries • Pulmonary perfusion
• Acute pulmonary embolism • Chronic thromboembolic pulmonary hypertension (CTEPH)

KEY POINTS

- Magnetic resonance (MR) angiography of the pulmonary arteries has proven clinical usefulness.
- Contrast-enhanced (CE) and non-CE angiographic techniques are widely available for high spatial and real-time imaging of the pulmonary arteries.
- Multiple-step protocols, such as MR perfusion followed by high–spatial resolution contrast-enhanced magnetic resonance angiography (CE-MRA), seem to be an optimal clinical approach for the assessment of different vascular diseases affecting the pulmonary arteries.

INTRODUCTION

Given the speed and robustness of modern multidetector computed tomography (MDCT) scanners, this technique has become the noninvasive gold standard for imaging of the pulmonary arteries.[1,2] The advantages of MDCT are fast examination with high resolution and visualization of even subsegmental pulmonary arteries. The technique is usually available 24/7 and allows exclusion of other causes of chest pain in the same examination. As a drawback, the amount of functional information is usually limited.

Direct visualization of the pulmonary arteries can be done using invasive techniques such as digital subtraction angiography (DSA), which are nowadays reserved for special preoperative settings, such as chronic thromboembolic pulmonary hypertension (CTEPH) and settings in which an invasive mean pulmonary arterial pressure measurement is required. Computed tomography (CT) and DSA have the inherent problem of irradiation and the need for nephrotoxic contrast agents.

MR imaging has evolved as a competitive noninvasive imaging modality.[3,4] Over the past decades MR imaging has undergone significant technical improvements such as faster acquisitions, larger coverage, and faster reconstruction, leading to substantially improved patient acceptance of this modality. Furthermore, the availability of MR systems has improved over the past years. These factors have positively influenced development of MR applications in the chest. The implementation of MR angiography (MRA), lung perfusion imaging, and the assessment of right heart function seem to be promising techniques for a comprehensive evaluation in patients with either congenital or acquired pulmonary arterial pathologies.[5]

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This review highlights the current state of various MRA techniques for the diagnosis of acute and chronic thromboembolic disease.

Technique

Different imaging strategies are available for imaging pulmonary arteries including CE and non-CE acquisitions. The most often used technique is high–spatial resolution CE-MRA.

Contrast-enhanced magnetic resonance angiography with high spatial resolution

CE-MRA consists of heavily T1-weighted gradient echo MR sequences after an intravenous injection of a paramagnetic MR contrast agent.[6] In general, 3-dimensional (3D) techniques with a relaxation time (TR) of less than 5 ms and an echo time (TE) of less than 2 ms are used for CE-MRA of the pulmonary arteries.[7] A short TR allows for short breath-hold acquisitions, and a short TE minimizes background signal and susceptibility artifacts. Nowadays, acquisition time has been shortened further using parallel imaging.[8] In parallel imaging, the image is reconstructed from an undersampled k-space in the phase-encoding direction and thus acquisition time decreases. With a typical acceleration factor of 2, every second line in k-space is skipped, which leads to reduction of scan time of approximately 50%.[9] This reduced acquisition time can also be traded for higher spatial resolution. The trade-off for the reduction of scan time or the higher spatial resolution is a decreased signal to noise ratio (SNR). It is inversely proportional to the square root of the acceleration factor times a geometry factor that is determined mainly by the coil design.[10] In the case of an acceleration factor of 2, the signal is at best 71% of the original signal.[10] Although an acceleration factor of 3 seems to be acceptable for the renal arteries,[11] an acceleration factor of 2 is usually recommended for the pulmonary arteries; this leads to high spatial resolution with a voxel size of 1.2 mm × 1.0 mm × 1.6 mm requiring a breath-hold of 20 to 30 seconds for acquisition. Artifacts in the center of the image can appear if acceleration factors of 2 are used in a coronal acquisition. To overcome this problem, patients are scanned with their arms above their heads, which could, however, cause discomfort in some patients.[8] The use of non-Cartesian, k-space filling techniques, such as radial and spiral image data acquisition, has also been proposed for use in the chest.[12,13] As breath-hold is crucial for image quality, the scan is generally acquired in the coronal orientation because the number of slices required for full coverage is lower than in other orientations (**Fig. 1**). This method requires a single injection of contrast. To improve spatial resolution and reduce the duration of the breath-hold, the sequential acquisition of 2 sagittal slabs covering the right and left lung separately has also been used successfully in patients with CTEPH.[14]

By combination of the latest technical developments, such as 32-channel chest coil, 3T MR imaging, high relaxivity contrast agent, and acceleration factor of 6, the acquisition of isotropic (1 × 1 × 1 mm^3) voxels covering the entire pulmonary circulation in 20 seconds is feasible.[15]

Contrast administration

For T1 shortening of the blood, a gadolinium (Gd) compound is injected in a peripheral vein as a bolus, preferably by an automated power injector. Mostly, standard-strength Gd compounds in a standard dose (0.1 mmol/kg body weight) are used for optimal opacification of the pulmonary

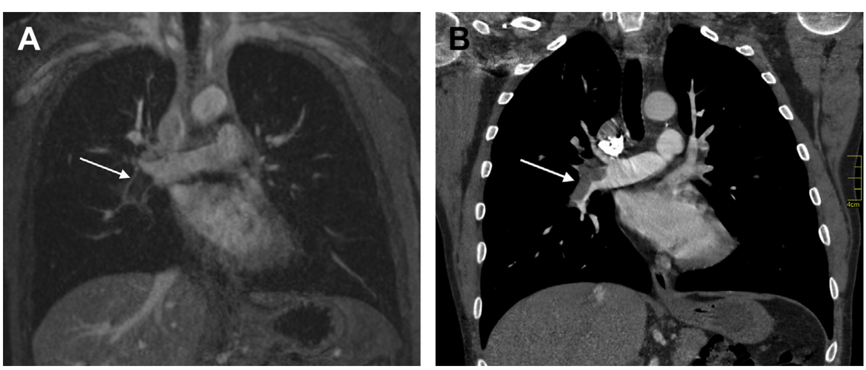

Fig. 1. (*A*) MR angiography in a 39-year-old man with central acute pulmonary embolism (*arrow*). The data set was acquired in a coronal orientation with a spatial resolution of 1.3 × 1.3 × 1.4 mm. Usually 2 to 3 angiographic phases are acquired even in patients with dyspnea. In this case, the second phase is shown demonstrating the thromboembolic material in the main right pulmonary artery. (*B*) Corresponding coronal reformatted CT angiography (4 days earlier) showed similar findings.