PICTORIAL REVIEW

Magnetic resonance imaging findings in acute pulmonary embolism

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ABSTRACT. Pulmonary embolism (PE) is the third most common acute cardiovascular disease after myocardial infarction and stroke, and results in thousands of deaths each year. Improvements in MRI accuracy are ongoing with the use of parallel imaging for angiography techniques and pulmonary perfusion. This, associated with other potential advantages of MRI (e.g. a radiation free method and better safety profile of MR contrast media), reinforces its use. The aim of this paper is to perform a pictorial review of the principal findings of MRI in acute PE. Acute PE can manifest itself as complete arterial occlusion and the affected artery may be enlarged. We report the main vascular and parenchymal signs, and an overview of current literature regarding accuracy, limitations and technical aspects is provided.

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Diagnostic strategies for pulmonary embolism (PE) have evolved over the last few decades with the development of new diagnostic methods. Initially, the time required for an MR examination and the lack of MR-compatible monitoring devices hindered the broad clinical acceptance of this method. Recently, significant technical developments in pulmonary MR angiography have occurred. Improvements include the use of parallel imaging, view-sharing, time-resolved echo-shared angiography [1, 2] and pulmonary perfusion. These techniques have shortened the acquisition time of MR angiography, improved spatial resolution and made it less susceptible to motion artefacts. In addition to classical MR angiography, other sequence types have been developed for more rapid acquisition of images and additional functional information.

The increased use of multidetector CT (MDCT) scanning has raised concerns about overall radiation exposure to the population, and has emphasised the need in the radiology community for optimised scanning protocols [3]. MRI does not require ionising radiation, or iodinated contrast media, and is associated with less renal impairment than MDCT. Thus, MRI appears to be the ideal imaging modality for use in ruling out PE.

The aim of this paper is to provide a pictorial review of MRI in PE diagnosis, and assess its accuracy through a review of the literature.

MRI technique

The proposed MRI protocol for PE diagnosis consists of real-time MR, MR perfusion imaging and MR angiography [3]. This basic evaluation protocol can be easily extended to match individual demands like the assessment of right and/or left ventricular function or the visualisation of the abdominal/pelvic and lower limb veins. The examination protocol first addresses fast overview sequences that ensure short examination times for use with patients in critical condition. Subsequently, the protocol presents a more comprehensive evaluation of the pulmonary arteries, for use with patients with less serious conditions (Table 1). The total time of acquisition is therefore dependent on the depth of the evaluation and lasts anywhere between 3 and 20 min. The achieved diagnostic accuracy is, at each step, balanced against the patient's condition (30–50 s for transverse real-time MRI, 180 s for complete real-time MRI and 7 min for morphological and MR perfusion imaging).

MR findings of acute PE

MR findings for acute PE were similar to those seen by CT or angiography, because all provided morphological representations of the same pathological process. We classified the MR features of pulmonary thromboembolism as vascular signs or parenchymal signs.

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Table 1. Example of a protocol for the diagnosis of pulmonary embolism. This protocol is based on Siemens sequences and the time of all protocol sequences is lower than 15 min. (Adapted from [5])

Sequence	Respiratory level	Diagnostic yield
T_2 weighted single shot half Fourier (T_2 HASTE)	Inspiratory breath hold	Cardiac morphology
T_1 weighted volumetric interpolated 3D gradient echo sequence (VIBE)	Inspiratory breath hold	Solid pathology, mediastinum
T_1 or T_2 weighted steady state gradient echo sequence (TrueFISP)	Free breathing	Pulmonary embolism, gross cardiac dysfunction
T_2 weighted inversion recovery fast spin echo sequence (TIRM, STIR)	Multiple breath holds	Mediastinal lymph nodes, parenchymal nodules
Respiration-triggered T_2 weighted fast spin echo sequence (T_2 TSE)	Respiration trigger	Mediastinal structures
T_1 weighted 4D contrast-enhanced first pass perfusion study	Inspiratory breath hold	Lung parenchymal perfusion
T_1 weighted 3D contrast-enhanced MRA	Inspiratory breath hold	Pulmonary angiogram
T_1 weighted volumetric interpolated 3D gradient echo sequence	Inspiratory breath hold	Solid pathology, mediastinal and pleural disease

3D, three dimensional; 4D, four dimensional. HASTE, half-fourier acquisition single-shot turbo spin echo; VIBE, volumetric interpolated breath-hold examination; TrueFISP, true fast imaging with steady state precession; TIRM, turbo inversion recovery magnitude; STIR, short T_1 inversion recovery; TSE, turbo spin echo; MRA, magnetic resonance angiography.

Pulmonary arterial signs

An abrupt decrease in vessel diameter, and absence of contrast material in the vessel segment distal to the total obstruction, are definite signs of PE and are demonstrated in MR angiography [4, 5] (Figures 1–5). Other

signs include a partial filling defect surrounded by contrast material, the “polo mint” sign on images acquired perpendicular to the long axis of a vessel, the “railway track” sign on longitudinal images of the vessel, and a peripheral intraluminal filling defect that forms acute angles with the arterial wall [5, 6]. All these

Figure 1. An 87-year-old female patient. (a) CT angiography clearly shows the central embolic material (arrow). (b) Coronal real-time MR, performed the same day, with similar information (arrow). (c) Transversal real-time image showing the saddle thrombus (arrows).

Figure 2. A 53-year-old male patient with an acute onset of dyspnoea. (a) Contrast enhanced CT angiography (arrow) shows peripheral intraluminal filling defect in sub-segmental vessel (arrow). (b) Clear visualisation of perfusion defects in the lung parenchyma (arrowheads).

Figure 3. (a) Contrast-enhanced perfusion images showing central thromboembolic material can be detected (arrow). (b) Clear visualisation of perfusion defects in the lung parenchyma owing to vascular obstruction, these defects are usually wedge-shaped (arrow).

findings are demonstrated in MR angiography, but can be suspected in perfusion studies. The use of MR venography could also help the diagnosis (Figure 6) [5].

Signs of pulmonary hypertension

Increased vascular resistance because of obstructed vascular beds leads to dilatation of the central pulmonary arteries. Enlargement of the central pulmonary

artery, when compared with ascending aorta, can be used indirectly to estimate the severity of the pressure, although this provides only a rough estimate, as individual pressure is heavily dependent on cardiac condition [5, 6]. As the right ventricular systolic pressure approaches that of the left ventricle, a paradoxical systolic motion of the interventricular septum is observed (Figure 7). Cine MRI is an accepted reference standard for assessing global and regional left and right ventricular function [5].

Figure 4. A 25-year-old female patient. (a) CT angiography shows thromboembolic material in both lower lobe pulmonary arteries (arrows). (b) High spatial resolution MR angiography demonstrates the same findings (arrows).

Figure 5. A 16-year-old female patient with swelling of the left leg. (a) CT angiography demonstrates thromboembolic material in the right (arrow) and left lower pulmonary artery. (b) High spatial resolution MR angiography performed using an intravascular contrast media. Both emboli were visualised; the image shows the thrombus in the right lower lobe (arrow). Also note the perfusion defect on right lower lobe. On the left side, the subsequent perfusion defect (dotted arrow) can be seen as an indirect sign of central vascular obstruction.

Figure 6. In the same patient as Figure 5 images were acquired in the steady-state phase of contrast media. A T_1 weighted gradient echo sequence (volumetric interpolated breath-hold examination VIBE) was used with an isotropic resolution of 1 mm. Images were acquired at approximately 5 min per 50 cm z-axis for 15 min examination time. Entire examination with first-pass pulmonary angiography was 20 min. Images demonstrate thrombotic material in the inferior vena cava (arrows in a,c) and the left popliteal vein (arrows in b,d).

(a)

(b)

Figure 7. Same patient as Figure 1. (a) Transversal T_1 weighted image after contrast media application. Note the main pulmonary artery is the same size as the adjacent ascending aorta (arrow). Also visible is thromboembolic material in both pulmonary arteries (dotted arrows). (b) A short axis image of the right and left ventricle. Arrows point to the interventricular septum, which is slightly bowed towards the left ventricle, indicating that pressure in the right ventricle is equal or greater to the systemic pressure.

Collateral systemic supply

In special pathological conditions (*e.g.* occlusion of the pulmonary arteries), flow through the bronchial arteries increases. With the improved spatial resolution of MR angiography, these can also be visualised with MRI [5].

Parenchymal signs

Visualisation of typical wedge-shaped parenchymal perfusion defects allows for fast and reliable detection of vascular obstruction, even at the subsegmental level (Figures 2, 3, 5 and 8). However, direct visualisation of the thrombotic material is often not possible.

Wedge-shaped pleura-based opacities from prior pulmonary infarctions are commonly seen in PE [6], and these can progress to parenchymal scars, bands, peripheral nodules, cavities or irregular peripheral linear opacities [5]. A mosaic pattern of perfusion is also seen with pulmonary MR perfusion in the presence of acute PE, or chronic thromboembolic pulmonary hypertension [5].

MR accuracy in detection of acute PE

A meta-analysis of studies that adopted gadolinium-enhanced MR for imaging acute PE used conventional

pulmonary angiography as the reference standard. A broad range of sensitivities, from 77% to 100%, was reported, with uniformly high specificities of 95% to 98% [7]. In other meta-analyses, the sensitivity of MR was 100% for PE in the central and lobar arteries, 84% in the segmental arteries, but only 40% in the subsegmental branches [8].

Recently, the PIOPED III trial [9] has shown that technically adequate MR angiography and venography had a sensitivity of 92% and a specificity of 96%, but 52% of patients (194 of 370) had technically inadequate results. They recommend that MR pulmonary angiography should be considered only at centres that routinely perform it well, and only for patients for whom standard tests were contraindicated [9]. However, this study has a major limitation; it did not include MR perfusion of the lung, which is defined as the most accurate assessment of PE [3].

For suspected acute PE, the accuracy of MR with a state-of-the-art protocol was both reliable and sensitive, compared with a 16-section CT [3]. The average MR examination time was approximately 10 min [3].

Limitations of MRI

The use of contrast agents based on gadolinium in nephropathic patients must be carefully conducted

Figure 8. (a) Wedge-shaped pleura-based opacities from prior pulmonary infarctions in right upper lobe (arrow). Because of vascular obstruction, these defects are usually wedge-shaped. (b) Contrast-enhanced perfusion images show perfusion defects in the lung parenchyma in the same lobe (arrowheads).

owing to the risk of systemic nephropathic fibrosis. In these patients, use of the low-dose or non-contrast techniques outlined in this article should be considered. In pregnant patients, gadolinium-based contrast agents are not proven to be safe and further improvement is needed in unenhanced MRI techniques, which currently allow accurate evaluation of only the central and first-order arterial branches [10].

Conclusion

MRI is emerging as an important tool in the diagnostic evaluation of patients with venous thromboembolic disease. Currently, the accuracy of this method is similar to 16-slice MDCT. This method is of particular interest for use in patients with allergic reactions to iodinated contrast media and in paediatric patients because it does not involve ionising radiation.

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