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Contrast enhanced pulmonary magnetic resonance angiography for pulmonary embolism: Building a successful program

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ABSTRACT

The performance of contrast enhanced pulmonary magnetic resonance angiography (MRA) for the diagnosis of pulmonary embolism (PE) is an effective non-ionizing alternative to contrast enhanced computed tomography and nuclear medicine ventilation/perfusion scanning. However, the technical success of these exams is very dependent on careful attention to the details of the MRA acquisition protocol and requires reader familiarity with MRI and its artifacts. Most practicing radiologists are very comfortable with the performance and interpretation of computed tomographic angiography (CTA) performed to detect pulmonary embolism but not all are as comfortable with the use of MRA in this setting. The purpose of this review is to provide the general radiologist with the tools necessary to build a successful pulmonary embolism MRA program. This review will cover in detail image acquisition, image interpretation, and some key elements of outreach that help to frame the role of MRA to consulting clinicians and hospital administrators. It is our aim that this resource will help build successful clinical pulmonary embolism MRA programs that are well received by patients and physicians, reduce the burden of medical imaging radiation, and maintain good patient outcomes.

1. Introduction

The importance of identifying pulmonary artery embolism (PE) is well established [1–8]. Unfortunately, symptoms are often non-specific, making a diagnosis of PE very challenging, based upon clinical presentation alone. As a result, imaging is frequently requested to exclude pulmonary embolus and the prevalence of disease in these patients is very low, often 5–10% [9].

Pulmonary CTA has become the widely accepted reference standard for diagnosis of PE. It is widely available in the emergency setting. CTA also requires only very short scan times using multidetector scanners, an important advantage when imaging severely dyspneic patients. CTA also allows for the assessment of other possible causes for the patient's symptoms. However, CTA has important drawbacks. First, it requires the use of ionizing radiation that can increase the risk of malignancy later in life [10]. This is especially troubling when imaging young patients. Second, it involves the use of iodinated contrast material that carries the risk of nephrotoxicity and occasional severe allergic reactions.

An alternative to CTA is contrast enhanced magnetic resonance angiography (MRA). With recent improvements in scanner technology, MRA shows tremendous promise in the task of detecting pulmonary embolism [11,12]. MRA requires neither the use of ionizing radiation nor the use of iodinated contrast. These advantages

Abbreviations: AP, anterior-posterior; CTA, computed tomographic angiography; DEM, Department of Emergency Medicine; DSA, digital subtraction angiography; EM, emergency medicine; GBCA, gadolinium based contrast agent; MIP, maximum intensity projection; MDCT, multi detector computed tomography; MRA, magnetic resonance angiography; PE, pulmonary embolism; PIOPED, prospective investigation of pulmonary embolism diagnosis; RL, right–left; SDCT, single detector computed tomography; SGRE, spoiled gradient echo; SI, superior–inferior; SSFSE, single-shot fast spin echo; SSPE, subsegmental pulmonary embolism; V/Q, ventilation/perfusion; VTE, venous thromboembolic event.

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make possible the routine use of multiphasic acquisitions and the potential for repeated contrast injections. This greater flexibility can lead to improved technical success rates through multi-phase acquisitions during a contrast bolus or the use of a repeated bolus and acquisition when the initial acquisition in the exam is compromised by poor bolus timing or patient motion [12].

There are, however, important disadvantages to MRA that have prevented it from being widely adopted for evaluation of pulmonary embolism. MRI examinations tend to be significantly longer than CT exams, limiting the suitability of long MRI protocols for severely dyspneic patients. The lower spatial resolution of MRA compared with CTA (~1–2 mm vs. <1 mm) has likely contributed to lower sensitivity for the detection of subsegmental pulmonary emboli [13–16]. Further, relative lack of familiarity with MRA for this purpose may also contribute to technical inconsistency, the primary reason for the underperformance of MRA for the detection of subsegmental emboli in the PIOPED III study [17–20]. Pulmonary MRA artifacts are also very different from those seen on CTA, and may reduce the accuracy of interpretation by radiologists less experienced with MRA.

Despite these challenges, we believe that pulmonary MRA is now emerging as a sufficiently mature technology to be used as a first line alternative to pulmonary CTA for the primary diagnosis of pulmonary embolism. Since 2008, our institution has offered a clinical pulmonary MRA program that has been embraced by our referring clinicians, including physicians in the Department of Emergency Medicine (DEM). To date, we have scanned more than 700 patients with MRA to evaluate for pulmonary embolus using a simple and robust imaging protocol requiring approximately 10 min of table-time. MRA is typically used for patients for whom CTA is contraindicated or who are more sensitive to ionizing radiation (children and younger adults). The purpose of this article is to share our experience and to provide practicing radiologists, emergency medicine (EM) physicians, MRI technologists, radiology department administrators, radiology residents, and MRI physicists with the tools to set up a successful clinical pulmonary MRA program at their own institutions.

2. Imaging protocol

2.1. Overview

Our pulmonary MRA protocol consists of six breath-holds, each lasting 15–19 s (Fig. 1). The total time in the scanner is less than 10 min (often as low as 5–6 min), only slightly longer than the table-time required for pulmonary CTA. The core angiographic acquisition is a rapid heavily T1-weighted 3D spoiled gradient echo (SGRE) sequence:

1. Three-plane single-shot fast spin-echo (SSFSE) localizers.
2. Pre-contrast T1 weighted 3D SGRE.
3. Pulmonary arterial phase T1-weighted 3D SGRE.
4. Immediate post-contrast T1-weighted 3D SGRE.
5. Low flip angle post-contrast T1-weighted 3D SGRE.
6. T1-weighted 2D axial or 3D SGRE with fat saturation.

Fluoro-triggering combined with elliptical centric k-space filling is recommended for timing of the pulmonary arterial phase. The lower flip angle of Acquisition #5 is chosen to better approximate the Ernst angle for blood with the lower intravascular contrast agent concentration at the time of the acquisition (~1–2 min following injection). Acquisitions #4 and #5 may also be helpful if transient effects related to the contrast agent kinetics decrease the diagnostic quality of the pulmonary arterial phase acquisition (Acquisition #3) [11,21,22]. A final post-contrast T1-weighted 3D spoiled gradient echo acquisition with fat saturation is performed to evaluate for any enhancing soft tissue abnormalities in the chest wall or upper abdomen. Typical acquisition parameters for pulmonary MRA (Acquisitions #2–5) are provided in Table 1. It would be relatively easy to include an additional, dedicated time-resolved dynamic perfusion scan prior to the pulmonary MRA itself. However, in the interest of keeping the exam time as short as possible, we did not include this in our clinical protocol. Fig. 2 shows representative images from a normal patient, illustrating the full chest coverage, visualization of vessels to the subsegmental level, and the rationale for the sagittal slab excitation. Fig. 3 shows examples of pulmonary embolism.

Table 1
Pulmonary MRA pulse sequence parameters for 1.5T.

Parameter	Value
FOV	35 cm SI × 28–35 cm RL × 26–34 cm AP
Matrix	256 × 192 × 128–140
True resolution	1.3 × 1.8 × 2.0–2.4 mm^3
Interpolated resolution	0.7 × 0.7 × 1.0–1.2 mm^3
Excitation slab	Sagittal
TR/TE	3.2 ms/1.1 ms, fractional readout
Flip Angle	28° (15° for 2nd post-contrast "low flip angle" scan)
Bandwidth	±83 kHz
2D parallel acceleration	3.72
k-space order	Elliptical centric
k-space coverage	Elliptical "corner cutting" (0.78 of fully sampled rectangle)
Scan time	14–19 s

2.2. Hardware

While MRA of the pulmonary arteries can be performed at 3 T—indeed, in our experience, the image quality at 3 T is excellent—the majority of pulmonary MRA studies performed at our institution are performed at 1.5 T due to wider availability of these scanners. All of the MRI scanner vendors offer commercial pulse sequences that can accommodate the needs of pulmonary embolism MRA. We use 2 different models of 1.5 T clinical scanners (Signa HDxt and Optima MR450w, GE Healthcare, Waukesha, WI) and use either an 8-channel coil (GE Healthcare, Waukesha, WI) or a 32-channel coil (32-channel Torso Array, NeoCoil, Pewaukee, WI; or GEMS Posterior/Large Anterior Arrays, GE Healthcare, Waukesha, WI) with 20–24 elements typically activated. Using a multichannel phased array coil with at least 8 channels facilitates the use of parallel imaging in the two phase-encoding dimensions. This helps to keep scan time to within a reasonable breath-hold (15–19 s) without compromising spatial resolution.

2.3. Slab excitation and parallel imaging

Excitation is performed in the sagittal plane, allowing the arms to remain at the patient's sides without any aliasing. The frequency-encoded readout direction is always oriented in the superior-inferior (SI) direction, the longest dimension of the imaging volume. We use a 2D auto-calibrated parallel imaging method [23] that results in a nominal 2-fold acceleration in each of the phase-encode dimensions (RL and AP). However, due to the need to acquire calibration data from the center of k-space during the scan, the net acceleration factor is ~3.7. Auto-calibrated methods [23,24] are generally preferable to methods requiring a separate calibration scan, due to potential differences in breath-hold position and potential calibration errors related to contrast administration between the calibration and the main acquisition. The scan time penalty to acquire auto-calibration data is relatively small.