Magnetic Resonance Imaging of Pulmonary Embolism: Diagnostic accuracy of contrast-enhanced 3D MRA, contrast-enhanced low flip angle 3D gradient echo and noncontrast steady-state free precession sequences

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Introduction: Acute pulmonary thromboembolic disease is a significant cause of morbidity and mortality, with estimated yearly incidence of 650,000 cases in the USA. Pulmonary computed tomography angiography (CTA) is the current gold standard for PE diagnosis. However CTA has limitations regarding the use of iodinated contrast and relatively high ionizing radiation burdens, a consideration given that many PE studies are performed in young adult females. Magnetic resonance angiography (MRA) has a potential role for PE diagnosis, shown in multiple studies. However, alternative MRA-like methods that further improve diagnostic accuracy and simplify the acquisition techniques remains an area of clinically important development. Conventional MRA requires precise bolus timing acquisition, which may be hampered by a symptomatic PE patient. Non-bolus timed and motion-insensitive alternatives would provide improved clinical robustness of MRA-like methods. Another MRA limitation is that it provides a lumen-only imaging; mural PE filling defects will lack conspicuity as these appear as dark signal against the dark adjacent lung. MRA-like alternatives that produce enhancing signal from the vessel wall, provide high contrast without need for bolus timing, and/or provide motion-insensitivity to respiration include low flip angle (FA) 3D gradient echo (3D GRE), or steady state free precession (SSFP) sequences.

Purpose: To evaluate the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of contrast-enhanced MRA, low flip angle 3D GRE and noncontrast SSFP sequences as part of a comprehensive MRI exam for the detection of PE in patients with CT-confirmed diagnosis.

Materials and Methods: ***Patients-*** This study was IRB-approved and HIPPA compliant. Inclusion criteria selected patients with CTA-confirmed diagnosis of PE between 8-2007 and 10-2009. Consenting patients had an MRI performed within 48 hours of the initial positive CTA. The final study population consisted of 22 patients with PE (13 female, 9 male). ***Acquisition- CTA:*** All bolus-timed exams were performed on a 64-slice scanner with images reconstructed at 0.625 mm slice thickness. ***MRA:*** Exams were performed on a 1.5 T system using multi-channel phased array surface coils. Chest imaging included: 1) breath-hold (BH) 15s acquisition time (AT) bolus-triggered contrast-enhanced 3D MRA, with standardized parameters including 40^{o} FA in coronal with axial reconstruction; 2) delayed phase 3D GRE with 12^{o} FA (VIBE, Siemens, Erlangen, GDR) with similar BH, AT and slice profile in axial and coronal; and 3) SSFP (TFISP, Siemens) in the axial plane with cardiac and respiratory gating. In 9/22 patients, additional VIBE delayed post-contrast imaging was acquired of the pelvis-to-knees for lower extremity deep vein thrombus (DVT). ***Image analysis-*** All MRI data sets were blindly evaluated (CT anatomic location of PE unknown) separately by two MRI experts. The presence or absence of thrombus within the pulmonary arteries was recorded for the 3D MRA, VIBE and TFISP images separately for each lobe of the lung, the right and left main pulmonary arteries, and separately for lower extremity DVT on VIBE images. A third reader, expert in CT, blinded to the MRA, retrospectively recorded presence or absence of thrombus in each pulmonary vascular territory; these results serving as the reference standard. ***Statistics-*** Sensitivity, specificity, PPV and NPV for the detection of PE was calculated for each MR-technique and also for the overall MRA exam (all techniques), with 95% confidence.

Results: Table 1 demonstrates the sensitivity, specificity, PPV and NPV for MRA detection of PE, in reference to CTA (note that no emboli were detected in the left main pulmonary artery). Overall, PE detection on 3D MRA images was 37/63 (59% sensitive, 99% specific), on VIBE images 47/63 (sensitivity 75%, specificity 100%) and TFISP images 43/63 (sensitivity 68%, specificity 100%). Combining all MRA images, the examination detected 54/63 pulmonary emboli, for a sensitivity of 86% [95% confidence interval = 74.1%-92.8%], specificity of 99% [93.2%-99.9%], PPV of 98% [89.0%-99.9%] and NPV of 91% [83.0%-95.5%]. In the 9 patients that had 3D GRE imaging of the pelvis and lower extremities, 5/9 (56%) were positive for DVT.

Conclusions: Our results lay the foundation for future clinical studies and technical development: We show 1) non-bolus timed delayed phase VIBE provides the most sensitive imaging for PE detection compared to standard bolus-timed MRA and non-contrast SSFP; 2) VIBE provides relative simplicity of technique with no bolus timing requirement, it may be repeated if a technical error is noted during acquisition; 3) combining the three imaging techniques further improved sensitivity for detection of PE. Another important observation is that PE within vessels of the lingula are detected with significantly lower sensitivity on all imaging techniques, which appears related to vascular geometry in addition to cardiac motion effects.

References: Kluge A, Luboldt W, Bachmann G. Acute pulmonary embolism to the subsegmental level: diagnostic accuracy of three MRI techniques compared with 16-MDCT. AJR 2006;187(1):W7-14.

Table 1: Statistics for the detection of pulmonary embolism with MRI

		Lobe (# of emboli)							
		Right main (1)	RUL (12)	RML (9)	RLL (15)	LUL (7)	Lingula (5)	LLL (14)	Combined
3D MRA	*Sensitivity (%)*	100	50	56	73	57	20	64	59
	Specificity (%)	100	90	100	100	100	100	100	99
	PPV (%)	100	86	100	100	100	100	100	97
	NPV (%)	100	60	76	64	83	81	62	78
3D GRE	*Sensitivity (%)*	100	69	78	80	57	40	86	75
	Specificity (%)	100	100	100	100	100	100	100	100
	PPV (%)	100	100	100	100	100	100	100	100
	NPV (%)	100	69	87	70	83	85	80	85
SSFP	*Sensitivity (%)*	100	58	78	73	71	40	71	68
	Specificity (%)	100	100	100	100	100	100	100	100
	PPV (%)	100	100	100	100	100	100	100	100
	NPV (%)	100	67	87	64	88	85	67	82
Overall MRI	*Sensitivity (%)*	100	83	89	93	86	40	93	86
	Specificity (%)	100	90	100	100	100	100	100	99
	PPV (%)	100	91	100	100	100	100	100	98
	NPV (%)	100	81	93	88	94	85	89	91