3D radial UTE MRI for Comprehensive Imaging of Pulmonary Embolism in Canines

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Target Audience: Physicists and clinicians interested in pulmonary MRA and pulmonary embolism (PE).

Purpose: To demonstrate the feasibility of using free-breathing 3D radial ultrashort echo time (UTE) MRI for comprehensive visualization of the lung vasculature and parenchymal structure by comparing its diagnostic efficacy and image quality to conventional pulmonary MRA.

Methods: Our institution's animal care and use committee approved the study. Twelve beagles were each imaged using MRI and CT on 2 separate days (before and after induction of PE). Animals were anesthetized and ventilated for all study procedures. On Day 1, autologous clots were made using 8 ml blood mixed with thrombin. Clots were allowed to mature for 24-48 hours at 4ºC in separate 1 ml syringes. On Day 2, 3 to 6 clots were injected into the right external jugular vein. CT imaging was performed during injection of 30 ml of iodinated contrast material (300mg/ml) on a 64-slice MDCT (Discovery STE, GE Healthcare, Waukesha, WI) in end-expiratory breath-hold with the following scan parameters: 64×0.625-mm collimation, 100 kV, 69mAs$_{eff}$, 0.5-s rotation time, and 1.4 pitch.

Thereafter, MR imaging was performed after injection of 0.03 mmol/kg gadofosveset trisodium on a 3 T scanner (MR750, GE Healthcare, Waukesha, WI). 3D MRA was performed in 3 phases (arterial "during") and 2 immediate delayed phases "post" contrast injection) [1]. Scan parameters were TE/TR=1.1/3.2ms, FA=28°, 2D parallel acceleration=3.72, k-space corner cutting, true resolution=1.3 x 1.8 x 2.0 mm^3, interpolated to 0.7 x 0.7 x 1.0 mm^3 through zero-filling. 3D MRA was followed by free-breathing 3D radial UTE over 5-6 min with the following scan parameters: TE/TR=0.08/4.2ms, 1ms readout (variable density gradients), FA=5°, 1.25mm isotropic resolution, 38,000 projections [2].

In a randomized, blinded fashion, a cardiothoracic radiologist marked and graded all pulmonary emboli on a 4-point scale (1=low confidence to 4=absolutely certain). The reader also scored the image quality of the pulmonary arteries (lobar, segmental and subsegmental) and the lung parenchyma on a 4-point scale (0=poor to 3=excellent). Locations and ratings of individual emboli were compared with the reference standard results of CT using alternative free-response receiver operating (AFROC) methodology. Mean values and standard deviations of image quality ratings were calculated and compared using t-tests.

Results: A total of 48 emboli were detected using CT in 11 of the 24 examinations. On a per subject basis, UTE sensitivity was 100 (CI: 71-100) and specificity was 92 (CI: 64-100). For MRA the sensitivity was 91 (CI: 59-100) and the specificity was 92 (CI: 64-100). On a per embolism basis, UTE detected 44/48 (91.7%) and MRA detected 40/48 (83.3%) emboli. The AFROC area under the curve (AUC) was higher for UTE (0.96; CI: 0.91-1) than for MRA (0.90; CI: 0.82-0.98), but this difference did not reach statistical significance (p = 0.078) (***Figure 1)***. The image quality of lobar pulmonary arteries was similar for UTE and MRA (2.9±0.3 vs. 2.8±0.4, respectively; p = 0.33). However, image quality on UTE exceeded that for MRA at the segmental (2.9±0.4 vs. 2.3±0.4; p < 0.0001) and subsegmental level (2.8±0.5 vs. 1.3±0.5; P < 0.0001) (***Figure 2)***. The visibility of the lung parenchyma was scored significantly better for UTE than for MRA (2.9±0.4 vs. 1.0±0.0, respectively; p < 0.0001). ***Figure 3*** illustrates the excellent conspicuity of even peripheral emboli with both techniques but with improved definition of the lung parenchyma on UTE images when compared to MRA images.

Discussion: 3D radial UTE imaging of the lungs provides comparable efficacy for PE detection and significantly better image quality for small vessels and the lung parenchyma when compared to conventional MRA imaging. In dyspneic patients who may have trouble breath-holding, it is likely that the free-breathing 3D radial UTE approach may show even greater improvements in performance relative to breath-held MRA.

Conclusion: 3D radial UTE for the detection of pulmonary embolism is feasible, and therefore worth testing in human patients.

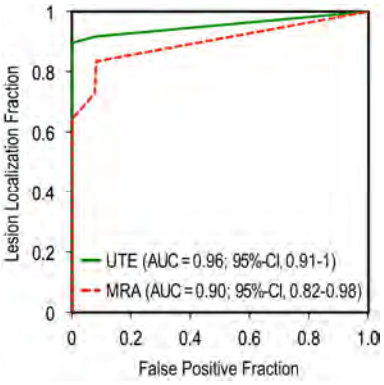

Figure 1: Alternative free-response ROC analyses of embolism detection. *The area under the curve (AUC) AUC was higher for UTE than for MRA, but did not reach statistical significance (p = 0.078).*

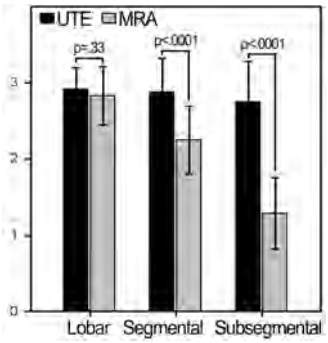

Figure 2: Image quality ratings of pulmonary arteries for UTE and MRA*. Bars represent mean values and the whiskers indicate standard deviation. Image quality with MRA imaging was lower than UTE in smaller vessels.*

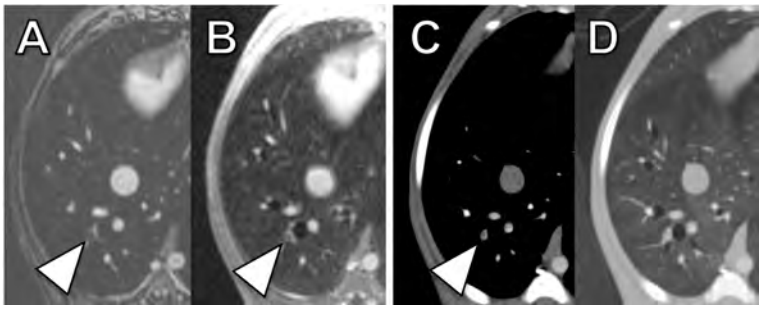

Figure 3: Visibility of pulmonary emboli and lung parenchyma using UTE and MRA. (A) *MRA,* ***(B)*** *UTE and* ***(C, D)*** *corresponding CT with arrowheads indicating a subsegmental embolus in the right caudal lobe. The image quality (i.e. visibility) of the lung parenchyma was rated as "1=fair" for MRA and as "3=excellent" for UTE. Note the ability to differentiate airways from lung parenchyma on UTE images.*

References: [1] Kalb et al Radiology 2012 [2] Johnson et al MRM 2013

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