Breath-held 3D radial MRI for simultaneous assessment of lung structure and function for detection of pulmonary embolism

Laura C Bell[1], Peter Bannas[2], Kevin M Johnson[2], Grzegor Bauman[3], Sean B Fain[1,2], Thomas M Grist[1,2], and Scott K Nagle[1,2]
[1]*Department of Medical Physics, University of Wisconsin - Madison, Madison, Wisconsin, United States,* [2]*Department of Radiology, University of Wisconsin - Madison, Madison, Wisconsin, United States,* [3]*Department of Radiology, University of Basel Hospital, Basel, Switzerland*

Target Audience: Scientists and clinicians interested in the detection of pulmonary embolism (PE).

Purpose: To demonstrate the feasibility of a dynamic contrast enhanced (DCE) breath-held 3D radial ultrashort echo time (UTE) acquisition to detect pulmonary embolism.

Methods: This study was approved by our institutional animal use and care committee. Twelve dogs (9.7 ± 1.0 kg) were each imaged at baseline health on Day 1 and following the injection of 3-6 autologous clots into the jugular vein on Day 2. The dogs were anesthetized and mechanically ventilated.

Image Protocol - 64-slice CTA scans (Discovery STE, GE Healthcare, Waukesha, WI) were performed as a reference standard. MR imaging was performed at 3T (MR750, GE Healthcare, WI) using a 32-channel phased array coil. For perfusion comparison, a conventional Cartesian DCE-MRI was acquired[3] (3.2 mm isotropic resolution; 1 sec temporal resolution). Following a 20 min delay to allow contrast washout, a single temporally interleaved 3D radial UTE acquisition[1] began simultaneously with the injection of 0.025 mmol/kg gadobenate dimeglumine at 1 mL/s with a saline flush of 10 mL. Acquisition parameters included TR/TE = 3.0/0.10 ms, 1 ms readout time, 10k projections, flip = 12º, 0.63 mm isotropic spatial resolution, and 1 sec time frames acquired over a 29 second breath-hold.

Reconstruction - The highly undersampled (345 projections/frame) dynamic 3D radial UTE images were reconstructed with a spatial-temporal constrained reconstruction algorithm[2] at 1.25 mm isotropic spatial resolution. To evaluate qualitative perfusion defects, 3D peak lung enhancement maps were calculated by performing a maximum intensity projection through time. A single time-average 3D radial UTE composite structural image was generated using all 10k projections at 0.63 mm isotropic spatial resolution.

Analysis - A cardiothoracic radiologist scored the Cartesian and 3D radial UTE images in a blinded, randomized fashion. UTE studies were each scored twice, first using only the lung perfusion images and second using both perfusion and the higher-resolution time-averaged structural images. Studies were scored on an 8-point confidence scale for PE (1 = "absolutely certain negative for PE" through 8 = "absolutely certain positive for PE"). Image quality of lung tissue was also scored on a 4-point scale (0 = "poor signal" to 3 = "excellent"). Receiver operating characteristic (ROC) analysis was done using CTA as a reference standard.

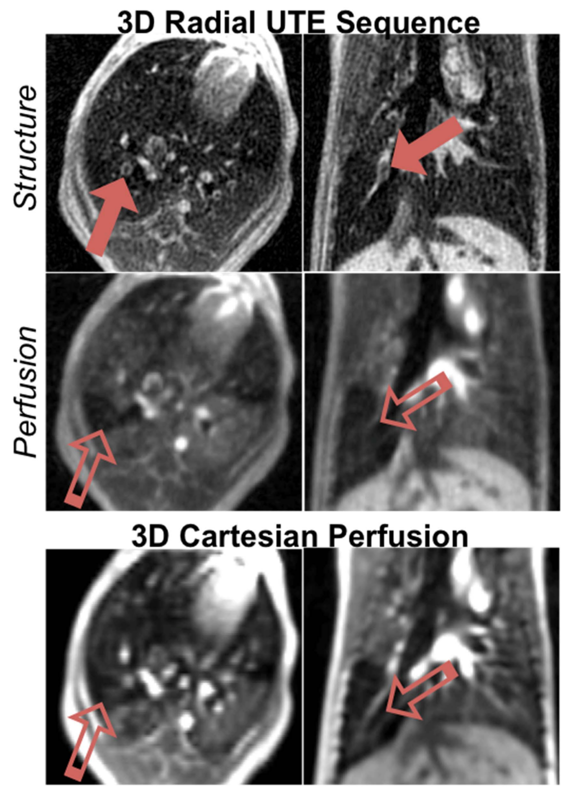

Figure 1: *A breath-held 3D radial UTE sequence provides high spatial resolution structure (PE indicated by solid red arrows) and qualitative perfusion (perfusion defects indicated by empty red arrows) for PE diagnosis. For comparison of UTE perfusion, a conventional Cartesian perfusion acquisition was also acquired (bottom row).*

Results/Discussion: Due to technical failure, the data from one dog was incomplete and therefore not included in the analysis. This resulted in 22 scans (11 animals, pre- and post-embolization). 3D radial UTE performed extremely well compared to CTA. When using both perfusion and high-resolution structural images, all scans were scored correctly regarding presence or absence of pulmonary embolism. The ROC area under the curve (AUC) did not differ significantly whether using perfusion images alone (AUC = 0.99; CI: 0.85 - 1.0) or using both the perfusion and high-resolution structural images (AUC > 0.99; 95% CI: 0.84 – 1.0; p = 0.41). Although the AUC of the Cartesian perfusion images (AUC = 0.86; CI: 0.64-0.97) was slightly lower than the UTE perfusion images this difference was not statistically significant (p > 0.18). A non-parametric t-test did, however, show that the reader was more confident with the PE diagnosis made with the 3D radial UTE than with the Cartesian acquisition (p = 0.02). This was likely due to worse image quality on the Cartesian images (p = 0.005) thought to be due to cardiac motion artifact.

Anecdotally, in one of the cases the CTA did not show any filing defects *after* injection of emboli, resulting in the reference standard determination of "negative for PE". In this case, a "false" positive diagnosis of pulmonary embolism that was made when using only the perfusion data (defect seen) was changed to a "true" negative diagnosis when high-resolution composite images (no PE seen) were included in the assessment. It is possible that in this case, the perfusion scan actually outperformed the CTA reference standard by identifying perfusion defects arising from small pulmonary emboli not visible on the CTA scan.

Conclusions: Breath-held 3D radial UTE can be used to visualize both lung function (perfusion) and structure (pulmonary artery filling defects) to successfully diagnose pulmonary embolism in an animal model. Furthermore, alternative diagnoses may be easier to detect using the improved ability of UTE to depict the lung parenchyma. These results support further evaluation of this method in human subjects.

Acknowledgements: NIH UL1TR000427 and the Department of Radiology R&D committee.

References: [1] Johnson KM et al., MRM (2011) 46 638-51 [2] Bauman G et al., MRM (2014) [3] Wang K et al., JMRI (2013) 38; 751-6