Stimulated echoes hyperpolarized helium-3 imaging: application to lung perfusion imaging

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Introduction

Simultaneous lung ventilation/perfusion imaging techniques using hyperpolarized (HP) ^{3}He have been successfully applied and demonstrated on small animals [1,2]. These techniques are based on the increased helium transverse magnetization dephasing rate induced by an intravascular contrast agent such as super-paramagnetic iron oxide nano-particle (SPIO). However, these techniques require a relatively large concentration of contrast agent and long echo time that may limit their applicability for human studies. In this work, we propose a new sequence based on stimulated echoes acquisition. This STEAM-based sequence takes advantage of the long helium T_1 values and allows acquisition of perfusion-weighted image with improved sensitivity to intravascular contrast agent.

Methods

The diagram of the modified STEAM sequence is presented in Figure 1. Non-selective pulses were used. Following the first two 90° pulses, a series of low α flip angle followed by radial imaging encoding gradients were applied. In order to avoid unwanted interfering echoes, spoiler gradients were also implemented. The main sequence imaging parameters were: 128 acquired samples, 200 radial directions per image, TR = 11ms, t_1 = 2ms, t_2 was varied between 10 ms and 15 s, α = 2°, FOV = 80mm. Images were acquired in the coronal plane.

MRI experiments were performed on a 2 Tesla magnet and ^{3}He was polarized using the spin-exchange technique with polarisation levels ranging between 20 and 30 %. The STEAM sequence was applied *in vivo* on 12 male Sprague-Dawley rats. The animals were anesthetized by intraperitoneal injection of sodium pentobarbital. A catheter was placed into a tail vein and connected to a syringe containing 1ml of contrast agent solution (SBPA, Bracco-Research, Geneva, Switzerland) with concentrations typically ranging between 0.5 and 3mg Fe/ml. The animals were tracheotomized and placed supine into the RF coil inside the magnet. For the imaging protocol, 8 ml of HP ^{3}He gas were insufflated inside the animal lungs. The contrast agent was than injected as a bolus. The STEAM sequence was triggered typically 1 to 2 seconds after the start of contrast agent bolus injection.

Results

Typical images obtained with the STEAM-based sequence are shown in figure 2. The left image was acquired without any contrast agent injection. Image in the center was obtained after injection of 1ml of contrast agent solution (0.5 mg Fe/ml). The image on the right was acquired two minutes later. The imaging parameters of these images are those given in the "Methods" paragraph with the t_2 time delay being equal to 15 s. A very large signal attenuation (in the order of 80 %) can be observed in the image acquired after the bolus injection. This signal attenuation can be explained as follows. During the first two 90° pulses, the contrast agent solution is passing through the lung vasculature. The ^{3}He spins flipped in the transverse plane experience extra-dephasing due to the presence of the contrast agent solution. The second 90° pulse stores half of the magnetization along the longitudinal direction. During the long t_2 delay, the contrast agent solution is diluted into the blood pool. As a result, the ^{3}He spin phase accumulated during the first t_1 time delay is not recovered after the low flip angle RF excitation.

As compared to gradient echo technique [1,2], this STEAM-based sequence appears to be more sensitive to the contrast agent susceptibility effect. This can probably be attributed to the fact that the accumulated spin phase during the first t_1 time delay arise both from susceptibility gradient and from bulk magnetic susceptibility frequency shift. Furthermore, compared to gradient echoes, stimulated echoes are less sensitive to inhomogeneity effects and image quality is substantially improved.

Conclusions

Simultaneous ^{3}He lung ventilation/perfusion images can be obtained with the new proposed STEAM-based sequence. This sequence, combined to the proposed imaging protocol, appears to be more sensitive to contrast agent effects than previous gradient-echo sequences. Further work would include dose-effect investigation and imaging sequence parameter optimization.

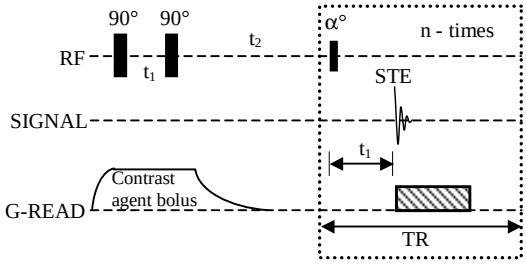

Figure 1. Schematic diagram of ventilation/perfusion NMR imaging using stimulated echoes.

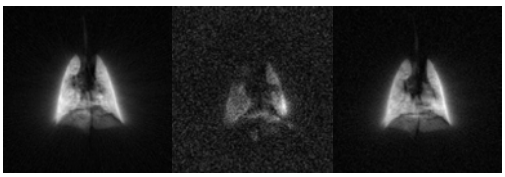

Figure 2. Ventilation images using the STEAM sequence of figure 1. Left: control image. Middle: image acquired with contrast agent injection. Right: control image acquired 2 minutes after the bolus injection.

References

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2. Stupar, V., et al., Invest Radiol, **38**, 334, 2003.