Automatic image registration of lung CT and hyperpolarized helium-3 MRI via mutual information of proton MRI

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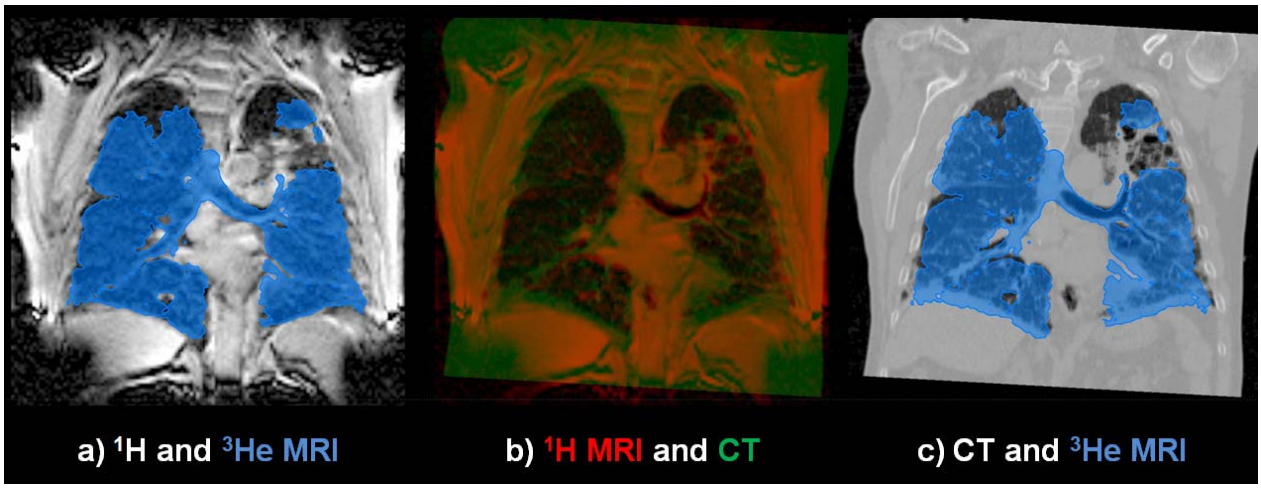
Introduction: Image registration of hyperpolarized helium-3 (^{3}He) MRI and CT could be beneficial in providing a combined anatomical and functional evaluation of lung physiology. Previously, image registration of ^{3}He MRI to CT has been attempted using manually-positioned control points [1] and improved MRI and CT acquisition protocols with replicated inspiratory states [2]. Preliminary work has also demonstrated the theoretical application of mutual information to provide an automatic registration of ^{3}He MRI to CT when the ventilation images are acquired in the same imaging session as a proton (^{1}H) MRI [3]. However, a major limitation of this approach was that separate breath-holds were required when acquiring the two sets of MR images, leading to small but inevitable alignment errors due to breath-hold variability. To alleviate this problem, a method of lung image acquisition of both ^{3}He MRI and ^{1}H MRI in the same breath-hold has recently been demonstrated [4]. A significant clinical application of this approach could be to assist treatment planning and post-treatment evaluation of lung cancer patients undergoing radiotherapy [1,5]. Therefore, the aim of this study was to test the feasibility of synchronous ^{1}H - ^{3}He MR image acquisition in lung cancer patients and to register the images to CT acquired for treatment planning.

Methods: Four non-small cell lung cancer (NSCLC) patients due to have radiotherapy gave written informed consent to undergo MRI for a study that was approved by the Local Research Ethics Committee. ^{3}He gas was polarized on site to 25% (GE Healthcare) and ventilation images were acquired during a single breath-hold of a 1L ^{3}He (300ml) and N_2 (700ml) mixture. ^{3}He MRI was performed on a 3T whole body system (Philips, Achieva) fitted with a second RF amplifier. With patients in the treatment position (arms supported in the upright position), ^{3}He MRI was acquired using either a prototype Helmholtz coil (Pulseteq, UK) or a quadrature birdcage coil (Rapid Biomedical, Germany) for ^{3}He transmit–receive (T-R). During the same breath-hold, the coil was actively detuned during ^{1}H transmit and ^{1}H T–R was performed with the scanner's ^{1}H quadrature birdcage body coil, which itself was actively detuned during ^{3}He T–R [4]. A spoiled gradient echo pulse sequence with sequential Cartesian phase encoding was used that consisted of a flip angle (θ=8°), TE=1.3 ms; TR=5 ms; 5x15-mm slices; field of view (FOV), 38 cm; 128x127 matrix; bandwidth/pixel, 500 Hz [4]. MR images were acquired before radiotherapy. On the same day as the MRI, radiotherapy planning CT was acquired on a 16 slice GE Lightspeed CT using an inspiration breath-hold technique to mimic as close as possible the MRI breathing maneuver [2]. The desired ^{3}He MRI to CT image registration was performed in two automatic steps. Firstly, the ^{1}H MRI was rigidly registered to the planning CT using a commercial implementation of mutual information [6] (Varian Medical Systems Eclipse radiotherapy planning system). Secondly, as the ^{3}He and ^{1}H MRI are acquired in a single breath-hold, they are assumed to be inherently registered. Therefore, the calculated transformation for ^{1}H MRI to CT was directly applicable to the ^{3}He MRI.

Results: All four patients tolerated the imaging procedure well and managed to hold their breath long enough for both sets of images to be acquired without any detrimental clinical effects. The ventilation images were successfully fused with the CT used for radiotherapy planning. The image registration procedure is demonstrated above. a) The ^{3}He MRI (blue) and ^{1}H MRI are inherently registered due to the single breath-hold acquisition sequence. b) The ^{1}H MRI (red) is used to automatically register the MRI to the planning CT (green). c) The ^{3}He MRI can be similarly registered to CT using the same image transformation.



Discussion: The use of a synchronous ^{1}H - ^{3}He image acquisition strategy provides single breath-hold ventilation and anatomical MR images and enables automatic ^{3}He MRI to CT image registration via the ^{1}H MRI. To our knowledge, this is the first report of automatic image registration of ^{3}He MRI to CT. The method is analogous to using the CT part of a PET - CT examination to facilitate PET image registration [7]. The additional anatomical information provides a robust method of registration. For ^{3}He MRI to CT, the presented automatic method of registration may be a useful supplementary tool for the planning and evaluation of lung cancer radiotherapy treatment and its side effects [1,5].

Conclusions: This preliminary work demonstrates the feasibility of synchronous acquisition ^{3}He and ^{1}H lung MRI in a group of lung cancer patients, and automatic registration of the ventilation images to CT via mutual information of an intermediate ^{1}H MRI.

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