Active Catheter Tracking in Air Cavities using a Semisolid Signal Source

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Introduction

Despite unresolved safety issues, active catheter tracking [1] is a well-established method to determine the position of devices in MR-guided intravascular interventions [2]. With its small sensitivity profile, a solenoid microcoil at the tip of an active tracking catheter serves as an excellent position marker. While these coils utilize the MR signal of the sourrounding blood, tracking coils need to be equipped with an independent signal source before they can be used in air-filled cavities of the body. Signal sources such as small water capsules or water-based gels showed very unstable results due to leakage, and are therefore unsuitable for long-term storage [3]. Inspired by reports on image artifacts from ventilation tubes [4], it could be shown that rubber materials can be used as signal sources [5]. In this work an active tracking catheter was constructed for use in the air cavities (e.g., the lungs) utilizing latex rubber as a signal source. The catheter was tested in phantom and animal studies using a dedicated MR pulse sequence in combination with a tracking algorithm.

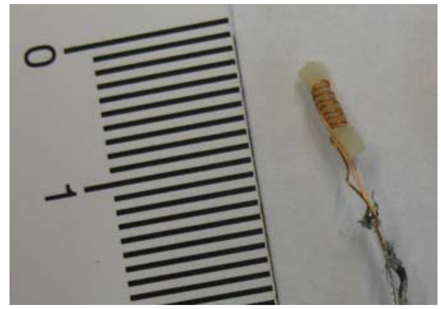

Figure 1: 3mm-long latex filled microcoil with 10 windings at the tip of a catheter

Materials and Methods

Material: To ensure biocompatibility, a sample of latex rubber from a clinical nasal ventilation tube (Rüsch, Germany) was retrieved. On the sample T2* measurements were performed in a clinical 1.5T whole body MR system (Avanto, Siemens, Erlangen/Germany) with an ultrashort-TE radial FLASH sequence using 10 different TE between 70 µs and 1.3 ms. Additionally, the T1 time was measured with a saturation recovery pulse sequence with 16 TI-times between 20 ms to 1400 ms. Results were: T1 = 90 ms, T2* = 0.9 ms and a spin-density of 57% compared to water.

Tracking Probe Prototype: A cylindrical piece of latex was used as a coil former (∅: 1.5 mm, length: 6 mm) filling a microcoil with 10 windings made from 0.18 µm magnet wire (Fig. 1). The coil was soldered to a coaxial cable to form an active tracking catheter. A polyurethan plastic coating was applied for water protection. The coil was connected to the MR system via a dedicated pre-amplifier built in-house.

Tracking Sequence: To track the catheter position a dual-echo tracking sequence was developed (Fig. 2)[6]. After a non-selective excitation pulse, two asymmetric echoes with TE_1 / TE_2 = 0.59 / 2.48 ms are sampled [4]. In addition to the encoding gradients a dephasing gradient (z-dephaser) is applied to suppress signals from homogenous background structures that are larger than the microcoil. Spatial encoding is performed for each spatial axis separately and is repeated with reversed gradient polarity to compensate chemical shift effects [1]. Also the dephasing gradient is moved to the remaining orthogonal direction. At a TR of 2.8 ms, the tracking block has a total duration of 2·3·TR = 16.8 ms.

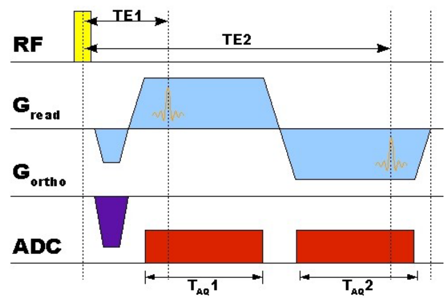

Figure 2: Radial double-echo sequence

Tracking Algorithm: After the Fourier transform of the projections, the magnitude data of the second echo was subtracted from the first to selectively enhance the signal from the short-T2* latex material. Data for the two gradient polarities were then multiplied at each location, and the coil position was determined by localizing the signal peak.

Phantom and Animal Experiments: All tracking experiments were performed on a clinical 1.5T whole body system (Siemens Magnetom Symphony). During imaging, the tracking block was either applied continuously, or the block was inserted into a real-time tracking sequence that offers a FLASH and trueFISP contrast. The catheter was used in a phantom consisting of plastic tubes in a water-filled tank that emulates the air-spaces of the lung. Additionally, the procedure was tested on a anesthetized and relaxed healthy pig. Ventilation was paused while the tracking probe was inserted into the lungs through the endotracheal tube. The position data was either retrospectively combined with a reference image set of the pig´s thorax or used for real-time positioning of the imaging slices.

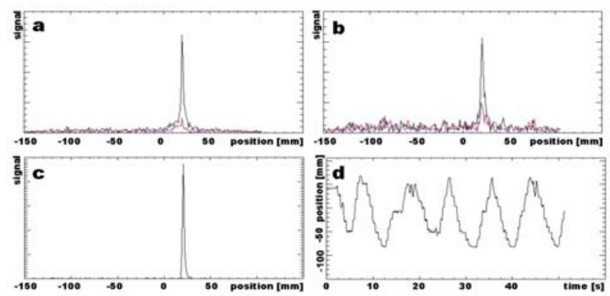

Figure 3: First (black) and second (red) echo with positive (a) and negative (b) gradient polarity. The latex signal is already partially decayed in the second acquisition. (c) After subtraction and multiplication only a single peak of the latex material is visible. (d)Position on z-axis while catheter is moved back and forth in the phantom for 60s

Results and Discussion

Figure 3 shows examples of position data from the two echoes. Background signal from larger structures, that is picked up by the coaxial cable, is suppressed by the dephasing gradients. In the second echo the remaining signal from water and surrounding tissue is removed by the subtraction, whereas the signal from the short-T2* latex remains visible. Subsequent multiplication to combine the effect of the z-dephasers and to compensate for chemical shift displacements enhances only the signal from the latex in the microcoil (Fig. 3c). The position of the probe can be easily depicted by localizing these signal peaks. The method remains stable even in the lungs of a living pig (Fig. 4) and provides position refresh rates up to 60Hz.

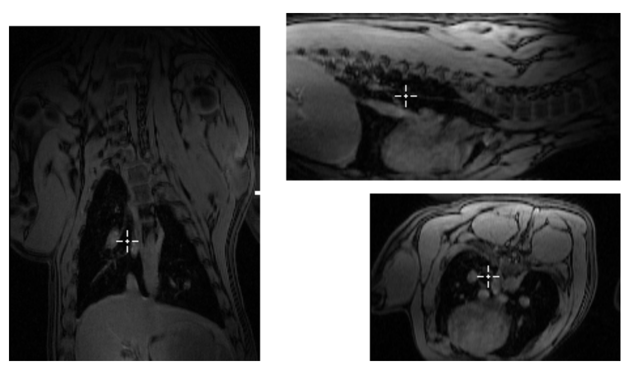

Figure 4: Coronal, sagittal and transverse views of the pig´s thorax. Device position is indicated by the white cross. Images were taken in a breathhold and the position data sampled at 15 updates per second.

Conclusion

An active microcoil loaded with latex rubber is an effective method to track invasive devices even outside the bloodstream. The dual echo acquisition can be used to enhance the latex signal with its submillisecond T2* to distinguish it from blood or tissue near the coil. In combination with dephasing gradients for the two orthogonal axes a stable tracking was achieved in the lungs of a living pig with a spatial resolution of 1.2mm.

References

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