Catheter Tracking and Visualization Using Perfluorocarbons in Interactive MR Fluoroscopy

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Introduction

It has recently been shown that MRI guided cardiac catheterisation is possible in patients using passive visualization of a CO_2 filled balloon angiographic catheter [1]. This enables the tip of the catheter to be seen provided it is in the slice plane, but does not allow for either automatic detection of the catheter tip or visualization of the entire length. Several active catheter localization techniques have been proposed to address these issues [2,3] but safety concerns have so far prevented active techniques from being used in-vivo. Optically detunable parallel resonant circuits have been proposed to address safety concerns [4]. However, the high switching speed required and the orientation dependent signal amplification are limiting factors. Also this device currently only enables visualization of the catheter tip, and it would be difficult to incorporate a large number of such devices on the catheter to enable visualization of the entire length without compromising the mechanical performance of the catheter.

In this work, we propose catheter tracking and visualization using perfluorocarbons in a standard angiographic catheter. The high sensitivity of ^{19}F (83% of protons) and the absence of detectable endogenous fluorine-containing metabolites in the human body enable exclusive visualization of the catheter. Two modes of operation are demonstrated: a) tracking mode, during which the tip is automatically localised in real-time and used to control the slice position of ^{1}H interactive imaging, and b) length visualization mode in which the entire length of the catheter can be seen at the expense of longer imaging time.

Methods

Catheter preparation: In this study, a 7F balloon catheter was filled with the blood substitute perfluorooctylbromide ($C_8F_{17}Br$) (PFOB) (Exfluor Research Corp.,Texas, USA), a substance currently in the process of phase III clinical trials [5]. The spectrum of PFOB acquired at 1.5T without volume selection from the catheter tip containing 1 ml of PFOB is shown in Figure 1. The chemical shift axis was arbitrarily centered at the resonances arising from the $(-CF_2-)_6$ atoms. Longitudinal relaxation times of the $(-CF_2-)_6$ group were measured to be approximately 1 sec. Given the large chemical shift range, only resonances between 4.5 and -4.5 ppm were used for ^{19}F imaging. For this purpose the excitation bandwidth was limited to 2 kHz. The receive bandwidth was adjusted as to allow a maximum shift of 0.35 pixel in the ^{19}F images leading to negligible spatial misregistration of ^{1}H and ^{19}F images.

Tip tracking: The standard, real-time interactive environment of a 1.5T whole body Intera system (Philips Medical Systems, Best, The Netherlands) was modified such that interleaved projections were acquired on the ^{19}F channel using a single-tuned rectangular transmit/receive surface coil. Using a projection based peak search algorithm, the coordinates of the catheter tip were extracted and a cross was overlaid onto ^{1}H SSFP images in real-time. Parameters for real-time interactive SSFP imaging were as follows: FOV: 350x350 mm^2, slice thickness: 50 mm, matrix: 128x96, flip angle: 45 deg., T_E/T_R: 1.2/2.4 ms, 62.5% half scan, acquisition duration of one image: 144 ms.

Visualization of catheter length: To allow visualization of the catheter length, non real-time ^{19}F SSFP imaging was employed with following settings: FOV: 210x165 mm^2, slice thickness: 20 mm, matrix: 192x192, flip angle: 60 deg., T_E/T_R: 2.4/4.8 ms. Scan duration was between 0.5-2 sec. using 1-4 signal averages, respectively.

Results

Figure 2 displays two out of the three orthogonal ^{19}F projections used to determine the position of the catheter tip. Reliable tip tracking was achieved for a variety of catheter configurations. The ability of visualizing both the tip and the length of the catheter is illustrated in Figure 3.

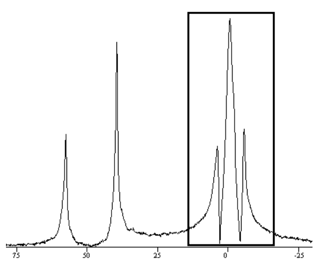

Figure 1: ^{19}F Spectrum of PFOB. The peaks resulting from the $(-CF_2-)_6$ atoms are centred at 0 ppm and are exclusively excited in ^{19}F imaging.

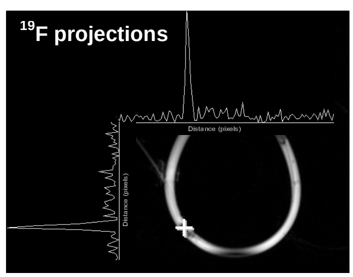

Figure 2: ^{1}H SSFP image of tubing with a 7F balloon catheter inside containing PFOB. Two orthogonal ^{19}F projections used to determine the position of the catheter tip (+) are shown.

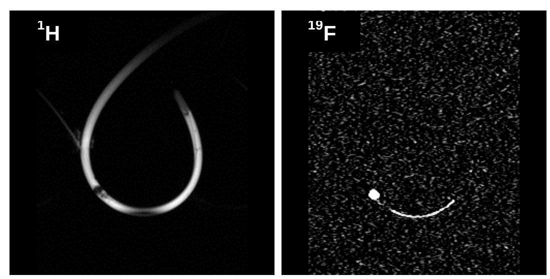

Figure 3: Corresponding ^{1}H (left) and ^{19}F (right) images of a 7F catheter. The catheter lumen is seen in the 19F image demonstrating the potential of the method for visualizing the catheter length.

Discussion

The lack of availability of safe and MR visible catheters is one of the main obstacles to widespread clinical use of MR guidance of endovascular procedures. It is necessary for these devices to be safe in terms of their mechanical stability, biocompatibility and their heating effects. It is highly desirable to be able to visualize both the tip and the length of a catheter, and for the device to be automatically detectable in the images. This work has shown that a standard angiographic catheter can be simply modified to meet all these requirements. There is no need for novel catheter designs, incorporation of electronic components into the catheter, or novel materials. This functionality is achieved by inserting a biocompatible perfluorocarbon into the lumen and balloon tip of the catheter, and modifying previously described catheter tracking software [6] to interleave ^{19}F tracking with real-time interactive ^{1}H imaging.

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