Intra-Arterial MRA based Roadmapping for Magnetically-Assisted Remote Control Catheter Tracking

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Introduction

We have been investigating magnetically-assisted remote control (MARC) endovascular catheters for interventional MRI procedures. MARC catheters contain microcoils on their tips that can be transiently activated by applying DC current [1]. The resulting magnetic moments created by the microcoils generate deflections that enable steering of the catheter into selected vascular structures. These steerable catheters have conductive elements running along their length and produce a magnetic field disturbance around the microcoils and wires when current is applied. While this magnetic field disturbance allows for passive visualization it also obscures the anatomy through which the catheter is being navigated. In this study we developed an alternate tracking approach that capitalizes on arterial access to generate selective intra-arterial angiograms that are used in a "roadmapping" mode to assure that vascular structures are not obscured when catheter deflections are applied. The concept is described and demonstrated in a swine model.

Methods

The technique is based on selective intra-arterial (IA) injections of dilute (1-2mM) gadolinium (Gd) contrast medium (Magnevist,) at the beginning of a dynamic MR angiographic acquisition. The angiogram is a thick slice 2D gradient echo sequence that can be obtained rapidly and requires only brief (~4s) IA Gd infusions (at 1-2cc/s) to highlight the vasculature. The low Gd concentration and short IA angiogram permits exceptionally low contrast doses and makes repeated evaluations practical. The initial angiogram is used as a roadmap that is subtracted from subsequent dynamic acquisitions, similar to conventional DSA practices. Keyhole methods are employed to increase the temporal resolution of the dynamic acquisition above that of the initial angiogram (typically>1fps). Advantages of this approach include the fact that local arterial anatomy is established at the outset and is retained throughout the acquisition period. It also permits very low SAR acquisitions which are necessary when catheters with conductive elements are present to minimize RF heating. Importantly, currents applied for catheter deflection, which produce considerable susceptibility artifact, will not obscure the previously established roadmap. The angiographic sequence is only moderately T_1-weigthed to allow for background signal that will be spoiled during microcoil activation, which will reveal microcoil position on the roadmap. The roadmapping approach was tested in a swine a model in which the carotid artery was accessed with a MARC catheter.

Results

The angiographic imaging protocol (FOV = 200X162mm, voxel dimensions = 1mm x 1mm x 8mm, TR/TE/α = 8.0ms/1.8ms/20^0, BW/pix = 192 Hz, SAR = 0.1 W/kg) was initially acquired in 1.3s while 2mM Gd-based MR contrast was injected at 2cc/s (Fig 1A). Subtraction of all subsequent frames began immediately and a keyhole factor of 60% was employed to achieve a frame rate of 1.33 fps. This balanced our ability to track smaller objects with an acceptable refresh rate. Blood flow rapidly washed out the IA injection (Fig 1B) to reveal the arterial roadmap on subsequent subtracted images (Fig 1, lower row). Activation of the MARC catheter produced a substantial artifact that scaled with applied current and locally obliterated imaging signal (Fig 1, C-E). The artifact created by MARC catheter activation was evident on subtracted images without obscuring the arterial anatomy, permitting catheter tracking during catheter deflection. Low level activation of the MARC catheter (10-50 mA) permitted catheter tracking without substantial deflection. Iterative updating of IA angiogram roadmaps permitted MARC catheter tracking over long distances and tortuous vessels.

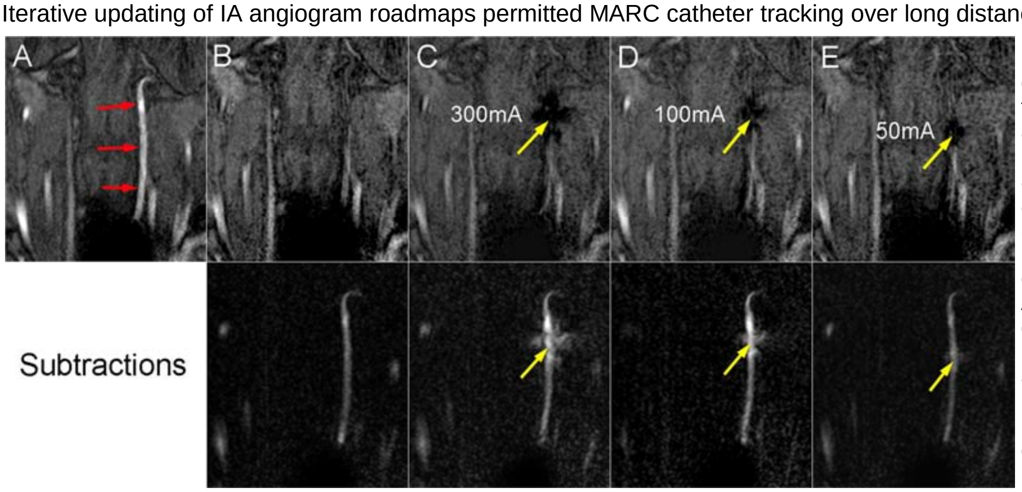

Figure 1: MARC catheter tracking is demonstrated in a swine carotid artery. In the first phase (A) a contrast enhanced MR angiogram is obtained via intra-arterial injection into the carotid to highlight local arterial structure (red arrows) and to create a mask for subsequent dynamics. Subsequent images are subtracted from the mask and reveal just the selected artery once the IA injection washes out (B). Activation of the deflection catheter at different current levels creates an artifact (yellow arrows) that obscures the local anatomy (upper row: C-E). Arterial anatomy is retained on the subtracted "roadmap" images (lower row) upon which the artifact generated by the MARC catheter can also be appreciated and tracked (yellow arrows).

Conclusions

IA MRA roadmapping is a simple, low SAR approach for tracking MARC catheters that allows for high temporal resolution. It requires minimal Gd dose, which allows for frequent roadmap updates, and does not obscure arterial anatomy during catheter deflection. The display is similar to that employed in digital subtraction X-ray angiography, which may ease adoption in the clinical setting.

References

[1] Settecase F, Sussman MS, Wilson MW, et al. Magnetically-assisted remote control (MARC) steering of endovascular catheters for interventional MRI: a model for deflection and design implications. Med Phys. 2007 Aug;34(8):3135-42.