Phased-Array Coil for Image-Guided Treatment of Occlusive Arterial Disease

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Motivation:

The presence of chronic total occlusions in coronary and peripheral arteries is a leading reason for selection of bypass surgery over less invasive interventions. Despite the benefits of percutaneous treatment, clinicians are often unable to traverse occlusions with catheter-based devices due to inadequate imaging capabilities provided by x-ray fluoroscopy. Limitations include poor visualization of the path through the lesion due to lack of intrinsic soft tissue contrast or iodinated agent in the occluded segment. There are also difficulties in identifying appropriate lesion entry points due to lack of three-dimensional information about proximal end geometry. In contrast, MRI can differentiate between the vessel wall and occlusive material. Moreover, catheter-based MR imaging techniques can be used to obtain high-resolution images of the proximal entrance of an arterial occlusion. In this work we describe a novel 'forward-looking' phased-array imaging coil designed specifically for intravascular MR imaging of occlusive arterial disease to facilitate lesion crossing.

Background:

Recently, efforts to build intravascular phased-array imaging coils have focused on opposed-solenoid designs [1]. Although this configuration is well suited for imaging the vessel wall in a patent vessel, a signal null exists directly in front of the catheter when it is oriented parallel to and within small angles of the static field (the natural orientation of most peripheral vessels). As such, it is impossible to obtain high-resolution intravascular images in regions directly in front of the catheter. To address this problem, we propose a phased-array coil configuration located on the tip of a catheter consisting of two solenoidal ellipses orientated at 45 degrees with respect to the catheter axis and oriented perpendicular to each other (Fig 1a). In this configuration, each solenoid is sensitive to MR signal in front of the catheter. By adding the magnitude of the signals received from each coil, the two sensitivity profiles are superimposed and there is an increase in the overall signal-to-noise ratio.

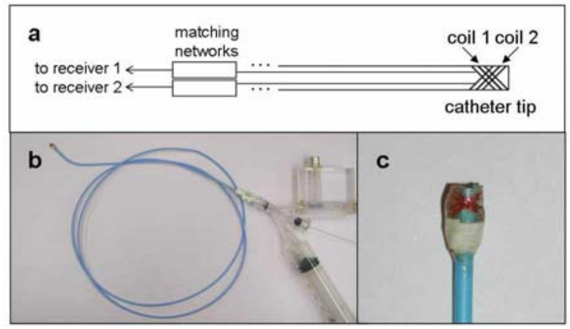

Fig 1. (a) Schematic diagram of the orthogonal solenoid imaging coil. (b) Prototype imaging catheter. (c) Magnification of catheter tip showing two orthogonal imaging coils.

Materials, Methods, and Results:

The sensitivity of the coil was simulated by using the theory of reciprocity and evaluating for the magnetic field produced by passing unit current through two orthogonal circular loops. The coil configuration was constructed at the tip of a 6F MP A2 angiographic catheter (Cordis Corporation). Each coil (30 AWG copper magnet wire, 3 turns, 4mm-outside diameter) was connected via 0.3 mm coaxial cable (Fujikura America Inc.) to matching networks located at the opposite end of the catheter (Fig 1). Imaging was performed on a 1.5 T GE Excite scanner (GE Medical Systems, USA) with the catheter inserted in a 2 % agar phantom. In-vivo imaging was also performed with the catheter placed in a femoral artery of a swine. For in-vivo studies, imaging was performed in cross-sectional planes through the artery directly in front of the catheter (SPGR, TR=6.9ms, TE=1.9ms, FA=20deg, FOV=8cm, 192x256, slice=1mm, time=1.3s; 2min post 0.05cc/kg Clariscan injection) to acquire information of vascular geometry for guidance purposes.

Results:

Simulations showed that by adding the magnitude of the MR signal from each coil it is possible to avoid complete signal nulls. The resulting sensitivity field is relatively homogeneous in the immediate region around the catheter tip and decreases with distance from the coils. The simulated sensitivity profile in a sagittal/coronal plane is shown in Fig 2a, 2b. The sensitivity field shown in phantom experiments matches the simulated sensitivity patterns well (Fig 2c). In-vivo images acquired with the catheter coil in front of the catheter clearly reveal branching vessels that were not evident when imaged with a conventional 3-inch surface coil (Fig 3). Such vessels must be avoided when steering a device into an arterial occlusion.

Discussion and Conclusion:

The proposed design is well suited for acquiring catheter-based images of the proximal end of arterial occlusions. Because the coil is also able to image the vessel walls simultaneously, it is well suited for guiding a device through an occlusion. Another advantage of the design is the ability to track the catheter using signal projection methods [2] in any catheter orientation as there will always be a net projected signal provided by at least one coil [3]. In most orientations where projection signal is available from both coils, there is added redundancy as tracking can be performed using both concentric coils on separate receivers with no acquisition time penalty. The orthogonality of the two solenoids is advantageous as there is no coupling between the coils and signal-to-noise ratio of the combined image is optimized [4]. A new phase-based method described previously can also provide catheter orientation information despite the concentricity of the two coils [5]. The imaging and tracking abilities of the catheter will aid an interventionalist in being able to identify entry points into a lesion and determining device position relative to the vessel wall so that the device can be kept within the occluded lumen during traversal.

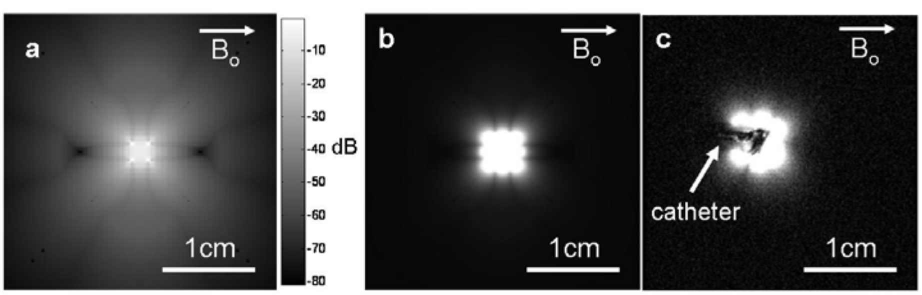

Fig 2. (a) Simulated sensitivity of orthogonal coil in a sagittal/coronal plane (no noise). Sensitivity is shown in decibels relative to the maximum sensitivity at the centre of the two coils. Good correspondence can be seen between the simulated sensitivity (windowed and leveled) (b) and an image acquired from within a homogeneous phantom (c). The catheter tip is seen in the phantom image as a void.

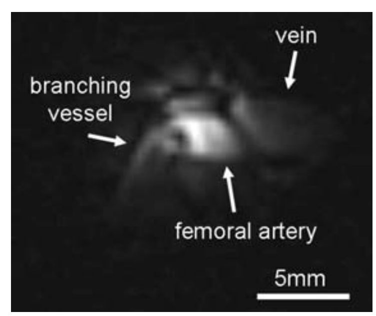

Fig 3. In-vivo image directly in front of catheter (cross section of artery). Small branching vessels can be seen.

References

[1] Hillenbrand C.M. et al. MRM 2004;51:668. [2] Dumoulin et al. MRM 1993;29:411. [3] Kuehne T. et al. JMRI 2003;17:620. [4] Roemer et al. MRM 1990;16:192. [5] Anderson et al. ISMRM 2003:2690.