Separation of Arteries and Veins in Equilibrium Contrast-Enhanced MR Angiographic Images

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Introduction: Contrast-enhanced MRA (CE-MRA) is useful for looking at vascular anatomy. However, it is difficult to capture the pure arterial phase. Often, poor timing with respect to the contrast bolus leads to venous enhancement, which degrades arterial visualization. A new type of Gd contrast, blood pool agents, will soon be available for CE-MRA. These agents stay within the intravascular space for a prolonged time, allowing for higher spatial resolution imaging compared to the currently available contrast agents. While blood pool agents can considerably improve the visualization of the peripheral vasculature, both arteries and veins will be enhanced, making methods to separate arteries and veins mandatory.

In this work, we have developed a unique combined acquisition and post-processing technique for arterio-venous separation in the peripheral vasculature, particularly focusing on the lower extremity (calf and foot). Since blood pool agents are not yet FDA-approved, we acquired high resolution 3D post-conventional Gd contrast equilibrium datasets to simulate blood pool datasets and evaluate the feasibility of our post-processing (segmentation) algorithm.

Methods: Standard peripheral CE-MRA using conventional Gd contrast agent (Omnipaque) was performed on the lower extremities using a Philips NT 1.5T system (Philips Medical Systems, Best, The Netherlands) and a phased array body coil. In addition, pre-contrast cardiac-gated 2D axial quantitative-flow (q-flow) phase contrast images (TE/TR = 4.8/8.3 msec, α = 30°, matrix = 256x256, FOV = 320x320 mm^2, 8 slices x 6mm) were acquired through the calf during peak systole to provide arterio-venous seed points for our segmentation algorithm. Approximately 60-120 sec following the arterial phase peripheral CE-MRA, a high-resolution 2 slab interleaved sagittal spoiled 3D gradient echo (T1-FFE) sequence (TE/TR = 2.1/20 msec, FA = 30°, matrix = 672x672x200, FOV = 440x154x200 mm^3 each calf, SENSE factor = 2.5, NSA=1) was acquired to simulate a blood pool equilibrium dataset.

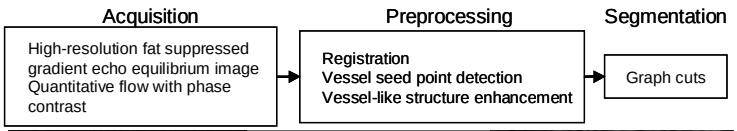
The q-flow images were registered with the 3D equilibrium dataset by first using the orientation stored in the images' DICOM tags to approximate the position of the axial images within the 3D dataset. Rigid body registration using mutual information [1] was then performed to correct for out-of-plane patient motion. A scale-based vesselness filter [2] was used to enhance the vessels in the 3D dataset and suppress the muscle, bone, and fat. The arterial and venous seed points, vesselness, and estimated width of vessels from the vesselness image were incorporated into a Markov random field framework for separating the arteries and veins. No user seed points are required for this technique, although users can add manual seed points if desired. The segmentation algorithm then uses the graph cuts energy analysis technique to minimize the Markov random field estimate [3].

Results: Four post-contrast equilibrium datasets of the lower extremity were segmented. The segmented arterial images were compared with the true arterial phase images (Fig 5 & 6 respectively). The main proximal branches of the crural arteries and veins were successfully segmented using the graph cuts algorithm. At the current spatial resolution, however, there is no clear spatial demarcation between some of the arteries and veins, as shown in Figs. 3 and 5 (arrow), resulting in some veins being labeled as arteries.

Discussion: Since conventional Gd agents diffuse out of the blood pool so quickly, the blood pool phase used here is less pronounced than with a true blood pool agent. Similar images acquired with a true blood pool agent would have considerably higher SNR, which will support the higher resolution necessary for a clear separation between arteries and veins.

Previous approaches to arteriovenous separation in blood-pool datasets have looked at either MRA image acquisition or steady-state data post-processing, and were applied to CE-MRA of the renal and upper calf areas [4-8]. We have focused on separating smaller vessels (1-6 mm diameter) in the lower extremities. The Markov random field framework allows us to incorporate additional imaging information, most notably automated arterial and venous seed points derived from phase contrast images and potentially vessel orientation. The graph cut-based segmentation algorithm is efficient and fast.

We have developed a clinically feasible technique that combines image acquisition with post-processing such that minimal user interaction is required for arterio-venous segmentation. Once blood pool agents become available, this technique may help simplify the interpretation of equilibrium phase MRA and make imaging multiple vascular territories easier, as no dynamic arterial phase will be necessary.



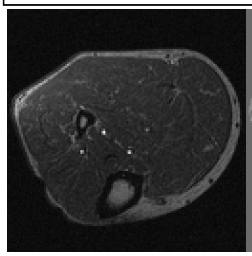


Fig. 1: Phase contrast magnitude

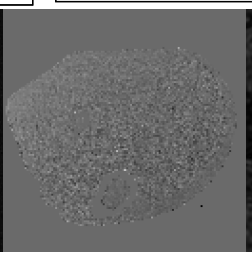


Fig. 2: Quantitative flow

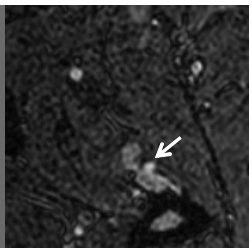


Fig. 3: No clear spatial demarcation between arteries and veins

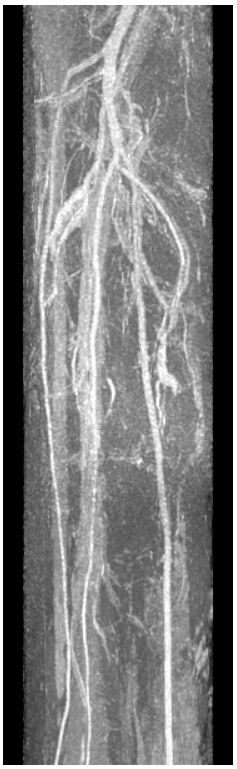


Fig. 4: 3D equilibrium

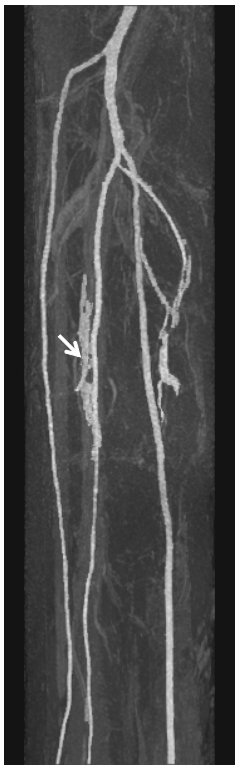


Fig. 5: Segmented arteries with veins and background 50% suppressed

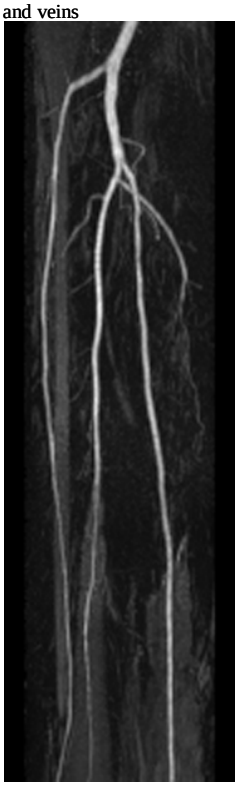


Fig. 6: Arterial phase

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References: (1) F. Maes *et al*., IEEE TMI, 16:187-98, 1997. (2) A. Frangi *et al*., Proc. MICCAI, 130-37, 1998. (3) Y. Boykov & V. Kolmogorov, IEEE PAMI, 26:1124-37, 2004. (4) Y. Wang *et al.*, JMRI, 12:661-70, 2000. (5) J. Svensson *et al*., JMRI, 20:49-57, 2002. (6) Y. Mazaheri *et al.*, JMRI, 15:291-301, 2002. (7) R. Stefancik & M. Sonka, Int J Cardiovasc Imaging, 17:37-47, 2001. (7) T. Lei *et al*., IEEE TMI, 20:689-703, 2003. (8) C. van Bemmel *et al*., IEEE TMI, 22:1224-34, 2003.