Artery-vein Separation of Ultra-High Resolution Contrast-Enhanced MRA using a Blood Pool Agent

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Introduction:

Using blood pool contrast agents (BPAs), ultra-high resolution MRA can be performed during the equilibrium phase (EP) of contrast enhancement. Because both arteries and veins are enhanced, however, we have implemented an algorithm to separate arteries from veins. The reliability of the algorithmically segmented arteries for diagnosing PVOD was determined by comparing the segmentation results with dynamic arterial phase MRA in a clinical evaluation.

Methods:

Ten patients with known PVOD received 0.03 (n=5) and 0.05 mmol/kg (n=5) of Vasovist™ (Schering AG, Berlin, Germany). Ultra-high resolution images of the lower extremity were acquired using a 3-station 18-channel phased-array peripheral vascular coil [1] on a Philips GyroscanNT 1.5T system (TR/TE 11.5 ms/3.2 ms, flip 31°, matrix 560x885x130, FOV 440x440x65 mm^3, slice thickness 0.5 mm, SENSE factor 4, NSA 1, bandwidth 92.6 Hz/pixel). [2] Artery-vein segmentation was formulated as a Bayesian estimation problem by modeling the posterior energy of the segmentation with prior and likelihood cost functions. The prior cost was a function of the vesselness measure and image intensity at each voxel while the likelihood cost was determined for voxels which were manually chosen as arterial or venous seed points. The posterior energy was minimized using binary graph cuts. A level set method was used to refine the graph cuts segmentation results. The manual interaction needed for seed point determination was limited to 3 minutes.

Three radiologists evaluated the segmented and arterial phase datasets obtained from ten patients (20 dynamic and 20 segmented calf datasets) in a blinded study. The datasets were randomized for each evaluator and displayed on an image viewer composed of maximum intensity projections and 3D multiplanar reconstructed views (Fig. 1). The readers graded the extent of stenosis for key arterial segments, presence of venous enhancement for key venous segments, and overall image qualities of SNR and vessel sharpness for each calf. The amount of venous enhancement and overall image measures were analyzed with the Wilcoxon signed rank test.

Results:

Figs. 2 and 3 show a representative example of the original EP data and its segmented arterial image. In all datasets, the main arterial segments were successfully segmented. In some cases, small arterial segments were missed in areas of low CNR (particularly the distal peroneal artery). The segmentation results corresponded well to the dynamic MRA with sensitivity, specificity, and accuracy measures ranging from 85-99% for the diagnosis of clinically significant (>50%) disease, as shown in Table 1. The venous enhancement scores for the dynamic and segmentation datasets are shown in Table 2. In 2 out of 3 readers, the segmented datasets had improved venous scores (reader 1, p=0.016; reader 3, p=0.001) with more venous segments rated as no enhancement. More venous segments were encountered in the dynamic datasets disturbing interpretation or rendering the image uninterpretable. Significant improvements in SNR (reader 1, p=0.012; reader 2, p=0.048; reader 3, p< 0.001) were noted by all readers and vessel sharpness (reader 1, p=0.037; reader 3, p< 0.001) in 2 out of 3 readers for the segmented datasets.

Table 1. Accuracy of segmented data compared to dynamic MRA for diagnosing clinical significant stenosis.

Parameters (%)	Reader 1		Reader 2		Reader 3	
Sensitivity	96	(44 / 46)	87	(48 / 55)	85	(61 / 72)
Specificity	98	(138 / 141)	99	(132 / 134)	91	(105 / 115)
Accuracy	97	(182 / 187)	95	(180 / 189)	89	(166 / 187)

Table 2. Distribution of image quality scores.

	Reader 1				Reader 2				Reader 3			
	Dynamic		Segmentation		Dynamic		Segmentation		Dynamic		Segmentation	
Venous enhancement												
None	65	(118 / 181)	77	(140 / 181)	48	(88 / 182)	8	(14 / 182)	57	(102 / 179)	73	(131 / 179)
Not disturbing	28	(51 / 181)	19	(35 / 181)	49	(89 / 182)	91	(166 / 182)	35	(62 / 179)	24	(43 / 179)
Disturbing	6	(10 / 181)	3	(5 / 181)	3	(5 / 182)	1	(2 / 182)	5	(9 / 179)	3	(5 / 179)
Not interpretable	1	(2 / 181)	1	(1 / 181)	0	(0 / 182)	0	(0 / 182)	3	(6 / 179)	0	(0 / 179)
Image SNR												
Excellent	15	(3 / 20)	55	(11 / 20)	10	(2 / 20)	15	(3 / 20)	0	(0 / 20)	95	(19 / 20)
Good	65	(13 / 20)	40	(8 / 20)	55	(11 / 20)	85	(17 / 20)	15	(3 / 20)	5	(1 / 20)
Moderate	20	(4 / 20)	5	(1 / 20)	30	(6 / 20)	0	(0 / 20)	80	(16 / 20)	0	(0 / 20)
Poor	0	(0 / 20)	0	(0 / 20)	5	(1 / 20)	0	(0 / 20)	5	(1 / 20)	0	(0 / 20)
Not assessable	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)
Vessel sharpness												
Excellent	10	(2 / 20)	40	(8 / 20)	20	(4 / 20)	5	(1 / 20)	0	(0 / 20)	50	(10 / 20)
Good	75	(15 / 20)	50	(10 / 20)	80	(16 / 20)	75	(15 / 20)	45	(9 / 20)	40	(8 / 20)
Moderate	15	(3 / 20)	10	(2 / 20)	0	(0 / 20)	20	(4 / 20)	55	(11 / 20)	10	(2 / 20)
Poor	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)
Not assessable	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)	0	(0 / 20)

Note.—Data are in percentages (count).

Discussion:

Complicating interpretation of the much higher spatial resolution EP images is the uniform enhancement of arteries and veins, which can obscure image interpretation. The statistical analyses showed that the segmented datasets were comparable to dynamic MRA. In addition, we have found several advantages of viewing EP datasets. Numerous foci of wall thickening (plaque) are visible, whereas they cannot be seen in the dynamic images. EP BPA imaging has higher venous CNR than does conventional imaging with extracellular agents. The segmented veins allow diagnosis of venous disease and malformations, such as varicosities seen in a patient with PVOD (Fig. 4). The viewer used in this study allows radiologists to view both the segmented and original EP datasets (Fig. 1) and change the opacity of blending between the two. This can compensate for small vessel segments that may be missed by the segmentation algorithm. In conclusion, an algorithm for artery-vein separation of EP BPA images requiring minimal user interaction was implemented and evaluated in a clinical setting for the diagnosis of PVOD. The segmented EP images compared favorably to the dynamic phase images with high sensitivity and specificity, and significantly improved venous suppression, SNR, vessel sharpness.

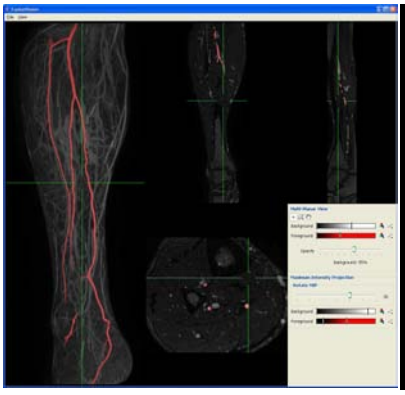

Fig 1. Clinical viewer allowing visualization of both original and segmented EP datasets.

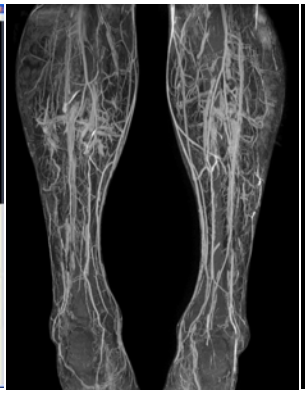

Fig 2. Unsegmented equilibrium dataset.

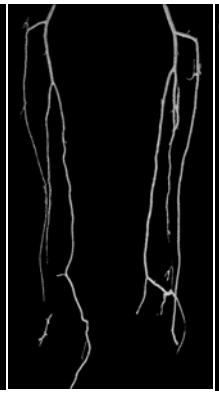

Fig 3. Segmented diseased arteries.

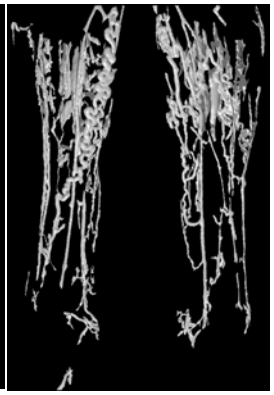

Fig 4. Segmented veins from patient with varicosities.

References: 1. JH Maki, CE Hayes, GJ Wilson, CM Mathis, RM Hoogeveeen. Proceedings of ISMRM 13th Scientific Meeting, p 454, Miami Beach, FL, May 2005.

2. MS Wang, DR Haynor, GJ Wilson, T Leiner, JH Maki, "Maximizing Contrast-to-Noise Ratio in Ultra-High Resolution Peripheral MRA using a Blood Pool Agent and Parallel Imaging," JMRI in press, 2006.

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