Measuring clot volumes using a watershed segmentation algorithm.

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Abstract: Recent thrombus within atherosclerotic plaque appears as a region of high intensity on T1 weighted fat suppressed images. Estimating clot volume is difficult as the signal intensity in both the plaque and the tissue background is heterogeneous. We have used a 3D segmentation technique based on the watershed method. In order to overcome the problem of over-segmentation, markers have been placed on the images marking the inside and outside of the thrombus. Interpolation is used to refine the segmentation. The user interface is quick and simple to use and reproducibility of the technique is acceptable.

Introduction: There is a predictable change in the T1 of blood as it undergoes clotting, with the resultant substantial reduction in T1 producing high signal intensity on T1-weighted images. We use this effect to detect methaemoglobin within recent thrombus in the carotid arteries using a T1 weighted 3D technique that suppresses the signal from fat and nulls that from blood [1]. In order to follow the progression of the carotid disease over time and to correlate the extent of the intraplaque thrombus with clinical symptoms it is desirable to measure the volume of the clot. This is a difficult segmentation problem as the clot volumes are very small and the signal intensity in both the clot and the tissue background is heterogeneous. Manual segmentation is very time consuming and threshold based techniques frequently fail as the intensity distributions in both the clot and the background are broad and overlapping. We have used a 3D implementation of the watershed algorithm [2] as it makes use of the edge information in the images. The problem of oversegmentation has been overcome by allowing the user to control the segmentation process interactively using markers.

Methods: A subvolume around the clot was defined and the user placed seed points on the images to mark pixels inside and outside of the volume of interest (Fig 1a). The image data was then smoothed and edge detection was then carried out using a 3D Sobel operator. The modified 3D watershed algorithm was applied to the edge image and the contours showing the clot region and the boundary between the clot and the background were superimposed on the images (Fig 1b). The user could review the position of the contours on each slice and if the initial watershed segmentation was unsatisfactory seed points could be added or removed. The image data was then interpolated to give a higher resolution and the watershed algorithm was reapplied to the pixels lying adjacent to or within the boundary regions. Finally the pixels remaining in the watershed region were assigned to either the background or the clot by comparing the intensity values to the mean intensities on either side of the boundary (Fig 1c). The program was implemented in IDL (Kodak, Boulder CO) and was designed to be simple and quick to use. In order to assess inter and intra observer variability and to look at the reproducibility of repeat studies 3 patients with carotid artery disease were selected and imaged twice with a pixel volume of $1.57 mm^3$. The slice positioning was modified slightly between the first and second scan. After initial training on a practice image, 3 observers then segmented each patient image 3 times. The order of the scans was randomised and processing was carried out during 6 separate sessions.

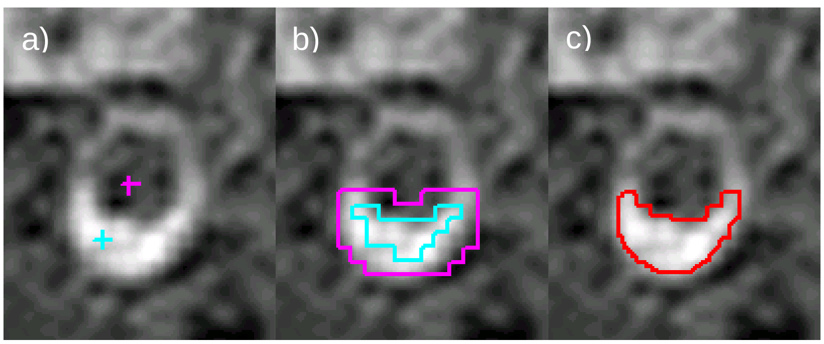

Figure 1.
The transverse slice cuts perpendicularly through the carotid artery. Signal from blood and fat is suppressed.
a) Position of seed points inside (cyan) and outside (magenta) the clot.
b) Watershed boundaries. Pixels in the region between the 2 contours are on the boundary.
c) Final segmentation

Results: The mean time to process a scan was 170 seconds, with the worst case taking 450 seconds. The results broken down by observer are summarised in table 1. Intra-observer variability was assessed by calculating the coefficient of variation (COV) of the 3 repeats for each study. The COV is below 10% in all but 3 cases. Inter-observer variability was assessed using the intra-class correlation coefficient (ICC) for a two-way mixed model. The calculated ICC of 0.91 suggests good agreement between the observers. The inter-scan reproducibility was very poor for patient 1 (COV=31%), reasonable for patient 3 (COV=10%) and excellent for patient 2 (1%).

Discussion: Segmentation of intra-plaque thrombus is a challenging problem and at present a robust fully automatic technique is not available. We have developed a technique that requires minimal intervention and which is very quick and simple to use. As with all semi-automatic techniques reproducibility is an issue. Intra-observer and inter-scan reproducibility was excellent for observer 1 who had the most previous experience with the segmentation technique. Observers 2 and 3 were inconsistent in their definition of the boundaries of the clot in patient 1 leading to poor results. This suggests the need for better training on the correct use of the program.

		Observer 1		Observer 2		Observer 3	
		Mean (mm^3) N=3	COV (%)	Mean (mm^3) N=3	COV (%)	Mean (mm^3) N=3	COV (%)
Patient 1	a	127	(4.1)	92	(59.5)	211	(44.0)
	b	122	(2.5)	126	(4.9)	139	(32.9)
Patient 2	a	219	(4.4)	209	(6.6)	206	(3.8)
	b	244	(6.6)	205	(3.2)	193	(8.2)
Patient 3	a	537	(1.8)	491	(7.1)	518	(8.7)
	b	537	(3.3)	577	(5.6)	443	(9.1)

Table 1.

References:
1. Moody A, et al., *Lancet*, 1999. **353**(9147):122-3.
2. Vincent L. et al. *IEEE Trans-PAMI*, 1991. **13**:583-598.