AORTA SEGMENTATION USING ELLIPTICAL DEFORMABLE TEMPLATES

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INTRODUCTION: Aorta segmentation is of great interest in many diagnostic tasks such as blood flow quantification and shear stress calculations; yet it is quite challenging as the aorta's shape, position, and blood flow profile varies significantly throughout the cardiac cycle [1]. Manual delineation is considered the gold standard; however it is a time consuming and observer-dependent process. In this work, elliptical deformable template based segmentation is proposed. The template assumes an elliptical equilibrium shape, but deforms to the underlying vessel shape thru a simulated annealing (SA) optimization process, which is governed by the shape constraints and local image features. The method is applied to the quantification of flow in MR phase contrast images of the ascending aorta. Comparison with manual analysis reveals that the proposed technique is reliable, fast, and can be useful in a clinical setting.

METHODS: Matlab (Natick, MA) was used for programming. Template deformation is restricted to the direction of the normal vector at each control point to speed up the computation. As an initial step, the algorithm requires the user to select a rectangular region of interest (ROI) that includes the vessel to be segmented in one of the high contrast images. This is the sole interaction of the user with the program. By selecting a high contrast image as the first frame to be processed, it is assured that the initial segmentation is successful as the results of this segmentation will be used as the initial contour configuration for other frames. The rest of the algorithm deals with deforming the template from its equilibrium shape to find the minimum energy configuration through simulated annealing. SA improves the segmentation accuracy by providing immunity to local minima [2], while a direct-ellipse fitting approach [3] provides a robust, computationally feasible, and rapid solution to make the tool practical. As an indirect, but computationally inexpensive measure of the shape energy contribution, the *continuity* and the *curvature* of the template are utilized as suggested in [4].

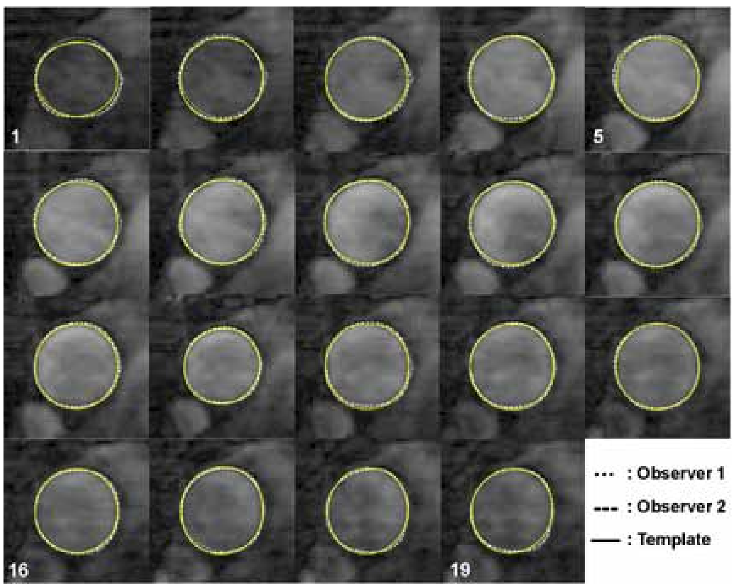

Figure 1: Elliptical deformable template ascending aorta segmentation results compared with two independent manual segmentation results.

RESULTS: After informed consent was obtained in accordance with our institution's investigational review board, MR studies were conducted on a 1.5 T GE scanner (General Electric, Waukesha, WI) on seven healthy subjects utilizing a phased-array cardiac coil. Ascending aorta MR PC images of all seven volunteers were manually segmented by two different observers in a blinded manner to assess the performance of deformable template versus inter-observer variability. Figure 1 shows the deformable template segmentation results of the fourth subject along with the manually traced boundaries. 19 frames were segmented on a PC workstation with a 2.4 GHz processor and 1GB of memory in 90 seconds with the deformable template technique versus 15-20 minutes for manual analysis. Average flow and average aorta area values are reported in Table 1. Cardiac outputs among the seven subjects cover a broad range within physiologic measures; hence they provide a diverse test bed for benchmarking. Correlation coefficients of estimated mean flow measurements between two observers, deformable template/ observer 1, and deformable template/ observer 2 are 0.97, 0.98, and 0.99, respectively. Similarly, estimated area measurements have correlation coefficients of 0.95, 0.96 and 1.0, respectively.

	Observer 1		Observer 2		Deformable Template	
Subject	Flow (liters/min)	Area (cm2)	Flow (liters/min)	Area (cm2)	Flow (liters/min)	Area (cm2)
1	5.32	5.31	5.74	5.49	5.59	5.53
2	5.23	7.51	5.31	7.42	5.43	7.44
3	4.83	8.14	4.84	7.70	4.77	7.71
4	5.89	8.44	6.00	8.52	5.88	8.34
5	3.90	8.03	3.79	7.75	3.66	7.73
6	6.38	8.93	6.71	9.27	6.36	9.06
7	7.28	8.50	6.85	7.82	6.96	7.76

Table 1: Estimated average flow and average ascending area values for seven subjects.

CONCLUSION: Anatomical a-priori shape information of vessels is incorporated into segmentation by setting the equilibrium shape of vessels to an ellipse. The shape energy is based on radial basis function; only non-affine transformations are penalized. Hence the method is not specific to the segmentation of a certain vessel. For less challenging vessel segmentation tasks in which the vessel shape changes and motion are less severe, one can either replace the simulated annealing based solution search with a simpler method or allow a faster cooling scheme for faster processing. A higher level of accuracy might be possible by resorting to second derivative information to detect boundary locations as mentioned in the discussion or by adding an extra energy metric that imposes a smoothness constraint in the temporal dimension.

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