Precision Measurement of Carotid Artery Stenosis Using the Isosurface Deformable Model and Skeletonization

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Introduction:

Precise measurement of the Degree of Stenosis (DoS) is important for management of patients with carotid artery disease. A novel methodology is presented here for precision measurement of DoS from contrast-enhanced magnetic resonance angiography (MRA).

Background

The Isosurface Deformable Model (IDM) is a novel methodology for reconstruction of the vascular surface from MRA (*IEEE Trans Med Imaging*, 2003; 22:875-81). The IDM is initialized interactively by defining an isosurface using the Marching Cubes algorithm. Isosurfaces of MRA typically have a realistic appearance but are not suitable for quantitative analysis since they are based on the subjective selection of the isointensity value. In the IDM, the initial isosurface undergoes a deformation process governed by objective criteria of the vessel boundaries. The total force that drives the deformation of each vertex of the surface is the weighted sum of three forces, $\overline{F}^{v-v}$, $\overline{F}^{t-t}$, and $\overline{F}^{v-i}$. $\overline{F}^{v-v}$ regularizes the vertex spacing, $\overline{F}^{t-t}$ smoothes the surface and $\overline{F}^{v-i}$ aligns the surface with ridges in the gradient magnitude of the image.

$$\overline{F}^{Total} = c_{v-v}\overline{F}^{v-v} + c_{t-t}\overline{F}^{t-t} + c_{v-i}\overline{F}^{v-i} \quad (1)$$

Ordered Region Growing (ORG) skeletonization is a method for delineating the centerline of tubular objects in grey-scale images (*IEEE Trans Med Imaging*, 2000;19:568-76). For any pair of points in the image, ORG skeletonization detects a unique optimal path between the two points. Centerline paths of vessels are obtained by interactively identifying a point at both a proximal and distal location along a given vessel.

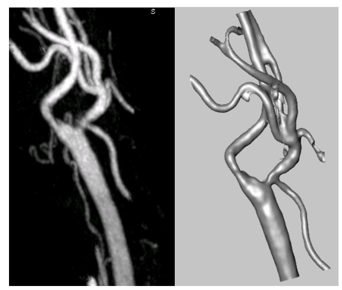

Figure 1

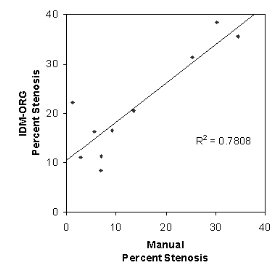

Figure 2

Methods:

IDM-ORG measurement of the degree of stenosis

The following method was devised for measurement of DoS of the carotid artery based on the IDM and on ORG skeletonization. First, the carotid artery surface is reconstructed from MRA using the IDM. The distance function is constructed relative to the carotid artery surface on a volumetric grid with an isotropic resolution of 0.25 mm. The distance function represents the minimum distance from each point in the volumetric grid to the surface. ORG skeletonization is then applied to the distance function to obtain the centerline of the internal carotid artery based on interactively identified points at proximal and distal locations Measurement of vessel radius is implicit in the detection of the vessel centerline; the radius of the vessel is the value of the distance function at the centerline. The DoS is then determined from the sequence of radii along the centerline. The normal vessel radius is then considered to be the mean of the radius of the 100 most distal of the points along the centerline. The minimum radius is considered to be the minimum of the mean of five consecutive points along the centerline.

Comparison of IDM-ORG stenosis measurement with manual stenosis measurement

DoS was measured independently by two observers in ten carotid arteries from contrast-enhanced MRA. Both observers measured DoS using both a manual method and IDM-ORG. Five of the MRA were obtained with the GE 1.5T EXCITE system and five were obtained with the Philips 1.5T Intera system. The manual measurement of the degree of stenosis was obtained from a maximum intensity (MIP) projection using the Vitrea workstation (Plymouth, MN). The MIP was obtained after sculpting, to remove extraneous tissue, using the orthographic perspective at an orientation that demonstrated the maximal vessel narrowing. The IDM-ORG was applied in a prospective manner; the parameters of the IDM-ORG were defined prior to the study with only one change made to offset the difference in the intensity range of MRA between the Philips and GE systems. The relative values of (c_{v-v}, c_{t-t}, c_{v-i}) were (2.0,3.0,10.0) for GE MRA and (2.0, 3.0, 2.0) for Philips MRA. DoS was defined according to the NASCET criteria.

Results

Realistic surface reconstructions wer obtained by the IDM (figure 1). Measurements of DoS using IDM-ORG are strongly correlated with manual measurements (r = 0.8836) (figure 2). DoS from IDM-ORG are greater than DoS measured manually (paired t-test, p = 0.002) with an average difference of 7.5%. Inter-observer variability in the measurement of DoS using IDM-ORG is significantly less than inter-observer variability in manual measurements (F-test, p = 0.0059). The measurement variability expressed as the standard deviation is shown in table 1.

Difference between observers using MIP	5.97%
Difference between observers using IDM-ORG	3.38%
Difference between MIP and IDM-ORG	4.87%

Table 1

Conclusions

The IDM-ORG is a promising approach for the precision measurement of carotid artery stenosis. Measurements of DoS with IDM-ORG are consistent with manual measurements but are significantly more reproducible.