Semiautomatic 3D segmentation and quantification of stenotic carotid arteries from CE-MRA by means of a B-spline tubular surface model

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Synopsis

The abstract presents the application of the 3D B-spline, tubular surface segmentation method for assessment of stenosis severity in carotid arteries (CA) from contrast-enhanced MRA. The stenosis grading follows NASCET standards. The method was evaluated on five phantom and one patient study. In the phantom studies we obtained a mean difference between stenosis grading of 2% (SD 8%) and correlation R^2=0.87. For the patient example the difference was below 2%.

Introduction

Automation of diagnostic methods can significantly improve its accuracy and repeatability leading to better conformity with international standards for stenosis assessment like NASCET [3] or ESCT. We intended to develop a method for semiautomatic segmentation of stenotic carotid arteries (CA) in contrast-enhanced MRA (CE-MRA). The result of such segmentation can be used directly for automatic quantification of stenosis severity in clinical practice.

Material and segmentation method

The segmentation method was applied to two kinds of data: **(i)** Five CE-MRA in-vitro phantom studies. Each vessel phantom, made of heat shrink tube had the same reference diameter (6.8mm) and diameters of the stenosic regions were as follows: 5.58mm, 4.69mm, 3.47mm, 2.92mm, 1.97mm. According to NASCET standard these diameters resulted in stenosis severity ranging from 18% to 71%. The images were acquired on a Philips 1.5T MR system with a T1-weighted 3D spoiled gradient-echo sequence. TR/TE/alpha 10/4.8/50°, FOV = 450mm with 80% RFOV, with a scan matrix of 256x182, reconstruction matrix 256x256, pixel size 1.758 x 1.758 mm, 3D volume slab thickness 72 mm, reconstructed into 60 slices with 50% overlap. **(ii)** CE MRA of patient CA acquired on 1.5T Siemens MR system with a T1-weighted 3D spoiled gradient-echo sequence. TR/TE/alpha 3.2/1.2/40° FOV 280x175mm, scan matrix 160x80, reconstruction matrix 256x256, pixel size 1.09x1.09mm slice thickness 1.67mm without gap in 54 slices.

We present a semiautomatic method, which requires minimal interaction: for each carotid branch the user has to select a proximal and distal point on a Maximum Intensity Projection (MIP). By means of Fast Marching Level Set Method [1] a centerline of the vessel is found, which is used to set the initial location of the 3D tubular structure for surface segmentation. Each carotid branch is represented by a B-spline surface, tubular structure. Surface location is determined by a number of control points. A typical configuration we used in segmentation of the stenotic Internal Carotid Artery consisted of 60 rings with 7 control points. Such tubular structures were fitted to the MRI data in a two-phase iterative process. A resulting structure is presented in **Fig.1** together with control points. The triangle vertices represent sampling points, where the image information was supplied during segmentation. In the presented case 25 sampling points were used inside each rectangle/patch specified by control points. Similar setting was also used for phantoms. The External Carotid Artery was segmented with the same number of control points, but with 9 sampling points per patch, as for a stenotic vessel a higher level of detail is necessary. This difference in density of sampling points can be observed as a difference of triangle size for the two branches. Further method description, together with the fitting procedure can be found in [2]. From obtained 3D surface model we computed the cross-section luminal area values in a number of planes perpendicular to the vessel axis. We used the NASCET standard for grading the stenosis severity; therefore we converted obtained values into diameters assuming a circular vessel cross-section. Then a ratio *100% (Dref – Dsten) / Dref* was used to find the stenosis grade. *Dsten* was a minimum value found along the vessel, then starting from this minimum we found the maximum diameter *Dref* in the distal vessel segment.

Results of quantitative evaluation

Automated segmentation was successful in all five phantoms. **Fig. 3** presents the resulting structure of the phantom with the most severe stenosis (71%). The segmentation setting is similar as the one used for ICA with stenosis. Results are presented in a form of the scatter plot in **Fig.4** Correlation of measured and physical degrees of stenosis gave a Pearson coefficient R^2= 0.87. Analyses of differences in Bland-Altman fashion showed AVG=2%, SD =8%. In the presented example of CA segmentation we compared the luminal area in cross sections with manually drawn contours, using the methodology of FWHM criterion as presented in [3]. Manually drawn contours resulted in 46% degree of stenosis, while from automatic segmentation we obtained 48%. Computational performance of the method depends on the number of control and sampling points. For ECA in a dataset from **Fig.1** it took approximately 3s for detection of the centerline and 12s for the surface segmentation (on a Pentium 4 – 3GHz computer).

Conclusions

We have received a good agreement between stenosis severity assessed on the vessel model resulting from our segmentation method and the true phantoms dimensions. For the in-vivo case we also obtained promising results. In the future we plan to test the method on a large number of stenotic CA cases. We plan to complement the method with an adaptive selection of the number of control and sampling points, as the presented examples indicated a need for a more dense distribution of points in stenotic region. In normal vessel segments a lower density of control points is better for preserving the vessel shape and for computational efficiency.

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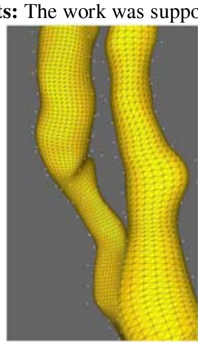

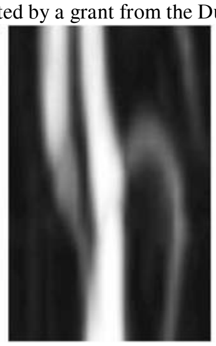

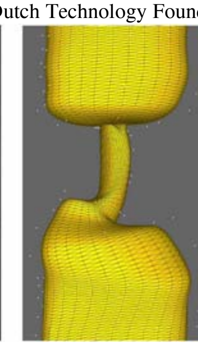

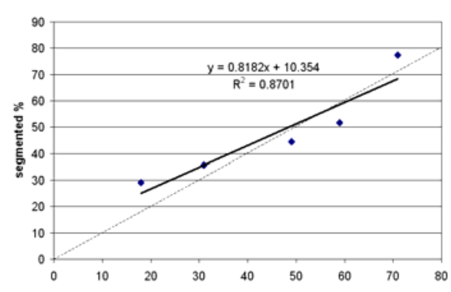

Fig.1 Segmented carotid bifurcation with 48% stenosis **Fig.2** Corresponding MIP of the vessel from Fig 1. **Fig. 3** Segmented phantom with 71% stenosis **Fig. 4** Correlation analysis of the agreement of stenosis severity grading

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