A 3D MRA Segmentation Method Based on Tubular NURBS Model

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Introduction

Volumetric contrast-enhanced Magnetic Resonance Angiography (MRA) images play an important role in the diagnosis of atherosclerotic diseases. Anatomical structures, as well as some morphological properties of carotid arteries can be intuitively perceived from 3D MRA. Vessel segmentation in MRA is a necessary step prior to further analysis, e.g. stenosis quantification and minimum diameter estimation for a stent placement. However, automatic 3D vessel wall segmentation remains a challenging task. Complex vessel structures, narrowing segments, intensity signal losses and kissing vessels are examples of main problems for the segmentation method.

Materials and method

Contrast-enhanced MRA images of carotid arteries from 10 patients having an indication of carotid artery disease were selected. For each patient, one side of the artery tree was chosen. An expert drew luminal contours on the 2D axial image slices starting from the common carotid artery proximal to the bifurcation point up to both internal and external branches. These contours were used as the `gold standard' to validate our method.

We developed an automatic segmentation method of 3D MRA based on Non-Uniform Rational B-Splines (NURBS) model of tubular structures. A NURBS model is a piecewise rational function defined by a set of knot vectors and control points with B-Splines as the basis functions. Two properties of a NURBS model, which are particularly important for our segmentation purposes, are (1) smoothness and (2) local property. The local property allows movement of a single point to locally fit the shape of the tube model into the vessel wall.

The initial tube model is defined by a set of circular rings centered at the vessel's centerline curve. A wave propagation method is used to automatically detect the centerline curve. A minimum of two-point clicks of user interaction is needed during the centerline detection to determine the proximal and distal points of the vessel area to be segmented.

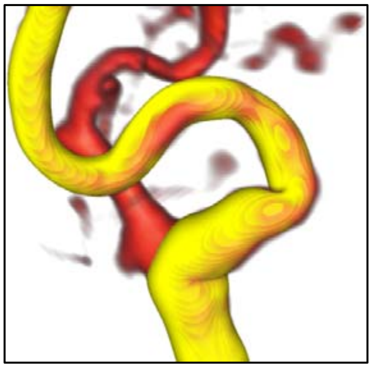

Figure 1. An example of MRA segmentation (yellow) .

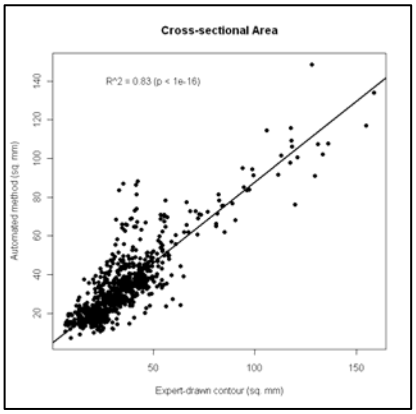

Figure 2. Linear regression plot of the cross-sectional area.

Two explicit forces drive the movement of control points: image forces and model forces. Image forces search the closest edge from a control point. A first derivative image gradient-based search is used to define the image forces. While the image forces move the control points in any directions with respect to the image gradient, the model forces constrain the movements to preserve the tubular shape of the final segmentation. The two forces must be kept in balance and we usually keep the model force relatively small to allow a flexible surface points movement in practice.

Results

A total of 831 sliced contours were used in this study from the selected ten patients. The average of percentage overlapped vessel area between the automated method and the expert-drawn contour was 65.18% (SD 10.66%). The correlation coefficient of the cross-sectional area between the automated method and the expert contours was 0.83 ($p < 1e-16$). The linear regression plot is given in Fig. 2. The agreement of the cross-sectional area was calculated using the Bland-Altman method (see Fig. 3). The mean difference of the cross-sectional area was 2.3 mm^2 (SD 10.1 mm^2).

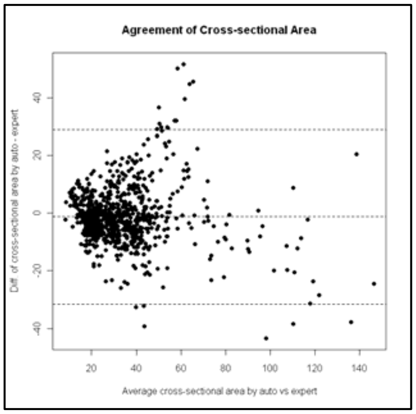

Figure 3. Bland-Altman plot of the cross-sectional area.

Discussion and conclusion

From the regression plot it can be observed that the cross-sectional area can be as large as 150 mm^2. This is due to the fact that axially sliced contour validation can result in an elongated vessel area, but even at these cases, the automatic method correlates well with the expert contour. At the bifurcation area, the automated method generally gives a larger area than the expert because the method delineates the whole bifurcation area, while the expert has chosen which branch to be segmented.

This study shows that a 3D tubular NURBS model can be used to segment volumetric vessel data. The model is flexible enough to incorporate two balancing image forces and model forces to fit the model's surface into the dataset. This makes the proposed segmentation algorithm a promising method to automatically segment 3D vessel structures.

Further improvements are anticipated. An extension to the full 3D bifurcation model is currently being developed and a more extensive validation on a larger datasets with cross-sectional expert-drawn contours is also an ongoing process.