Shifting of the Aneurysm Necks for Enhanced Aneurysm Labelling

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Abstract. Volume representations of blood vessels acquired by 3D rotational angiography are very suitable for diagnosing an aneurysm. We presented a fully-automatic aneurysm labelling method in a previous paper. In some cases, a portion of a "normal" vessel part connected to the aneurysm is incorrectly labelled as aneurysm. We developed a method to shift the erroneous borders as close to the real aneurysm as possible. Application of this method gives better estimates for the aneurysm volumes.

1 Problem

Volume representations of blood vessels acquired by 3D rotational angiography show a clear distinction in gray values between tissue and vessel voxels [1]. These volume representations are very suitable for diagnosing an aneurysm (see Fig. 1.1).

Physicians may treat an aneurysm by filling it with coils. Therefore, they need to know the volume of the aneurysm. In a previous paper [2] we described a method for fully-automatic labelling of the aneurysm voxels after which the volume is computed by counting these voxels (see Fig. 1.2).

We use local distance thresholds to define a tight bounding surface around the aneurysm [2]. This tight bounding surface should be located just outside the aneurysm where it borders to tissue. Elsewhere, it should intersect the "normal" vessel as close to the aneurysm as possible. The local distance thresholds are derived from border vessel voxels (i.e. vessel voxels face connected to a tissue voxel). Because border vessel voxels are missing at an aneurysm neck, the tight bounding surface may bulge out into a "normal" vessel part (see Fig. 1.2). In such a case a portion of this "normal" vessel part is incorrectly labelled as aneurysm. The problem is to correct these erroneous labelled border areas.

2 Related work

Subasic et al. [3] use the level-set algorithm with a 3-D deformable model for segmentation of an abdominal aortic aneurysm from CTA images. Because their method is adjusted to the shape of the abdominal aorta, it cannot be used free from problems for an arbitrary aneurysm.

McLaughlin et al. [4] demarcate the extent of an intracranial aneurysm given a 3-D model of the vasculature. Local shape descriptors are grouped using a novel region-splitting algorithm. The method is used to estimate aneurysm volume. Results are presented for four clinical data sets.

Bruijne et al. [5] use model-based interactive segmentation of abdominal aortic aneurysms from CTA data and multi-spectral MR images. After manual delineation of the aneurysm sac in the first slice, the method automatically detects the contour in subsequent slices.

3 What is new

To improve the accuracy of the estimated aneurysm volume, we have developed a method to shift an erroneous aneurysm neck along the corresponding vessel part as close to the real aneurysm as possible. We use the shape information extracted from this vessel part to control this shift.

4 Method

Fully-automatic improvement of the estimated aneurysm volume is performed in four steps. First, the fully-automatic branch labelling method [6] is applied. Next, we check whether the local shape properties indicate that a neck may be shifted (see Section 4.1). If yes, then the erroneous aneurysm voxels in front of this neck (i.e. farther away of the real aneurysm) are changed to "normal" vessel voxels, and next this neck is shifted till the "normal" vessel part evolves into the real aneurysm (see Section 4.2).

In our system shape information extracted from a "normal" vessel part is stored in a *tube object* (tube for short). A tube consists of a series of consecutive probes [7]. A *probe* is a combination of a sphere, a plane through the center of the sphere and a number of shape parameters. After a tube is created by fully-automatic vessel tracing [6], the sphere centers are close to the central axis of the vessel, the planes are almost orthogonal to the vessel and each probe contains an ellipse representing the local cross-section of the probe's plane with the vessel surface. Note that the fully-automatic branch labelling method is extended to create also a node for each aneurysm neck.

4.1 The Conditions for Shifting of a Neck

To prevent erroneously shifting of a neck a number of conditions must be fulfilled, the most important ones are:

1. It is possible to align a probe [7] (from now on called the *"neck probe"*) at the neck node.
   Successful alignment indicates that the vessel has approximately a cylindrical cross-section at the neck node.

2. The diameter of the vessel at the neck should be sufficiently smaller than the diameter of the aneurysm, else, the neck may be inside the real aneurysm.
3. It is possible to generate a tube (see Section 4) by fully-automatic vessel tracing [6] along the best valid run-up path to the neck node.
   A run-up path consists of branches of the generated graph [6]. A run-up path is valid if the last part of the run-up path is inside the run-up region. This run-up region is a truncated cylinder enclosing the "normal" vessel part at the neck. Both the length and the radius of this cylinder are given by radius of the neck probe. The normal of the neck probe gives the central axis of this cylinder.
   If there are more valid run-up paths, we select the run-up path which stays as long as possible inside the halve cylinder, created by extending the run-up region farther away from the aneurysm. If there are still more valid run-up paths, we select the run-up path with the greatest Euclidean distance between the begin of the run-up path and the plane of the neck probe. If there are still more, we select the run-up path with the greatest length.
   The generated tube is also used to refine the run-up region.
4. The aneurysm is separated from the refined run-up region except at the neck.
5. The generated tube contains enough aligned probes to extract the radius threshold r_{shift} from the radii of these probes (details not in this paper). r_{shift} (just greater than the vessel radius at the neck) is used to detect where the vessel part evolves into the real aneurysm.

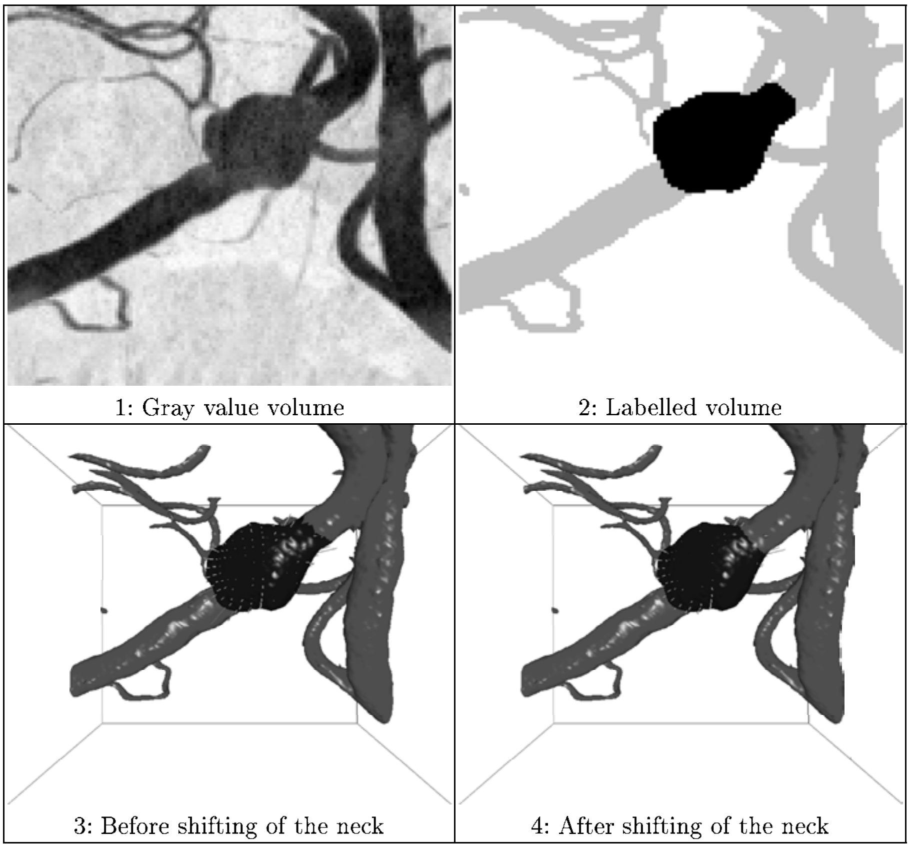
4.2 Cleaning and Shifting

All aneurysm voxels in the refined run-up region are changed to "normal" vessel voxels. After that, possible aneurysm voxels in the vessel part farther away from the neck are probably disconnected from the real aneurysm. These isolated clusters of aneurysm voxels are also changed to "normal" vessel voxels.

Starting at the neck node, the erroneous voxels closer to the aneurysm center are corrected by moving a test probe in small steps along a growing path (the *"shift path"*) of face connected vessel voxels. All face neighbor vessel voxels of the current voxel of the shift path, closer to the aneurysm center, are candidates to extend the shift path. If there are more candidates, we select the candidate closest to the vessel center. If there are still more, we select the candidate with the smallest Euclidean distance to the probe. For each new voxel the probe is first moved to the position of this voxel and next aligned [7] to extract the local direction of the vessel.

For each position of the test probe we collect the vessel voxels located in a small cylindrical slice at the front side of the plane of the probe. The radius of this slice is equal to radius threshold r_{shift}. The central axis is given by the plane normal of the probe. The thickness is equal to the size of a voxel times 2.5. The factor 2.5 is carefully chosen: a much smaller factor resulted in disjunct vessel voxels in case the plane is oblique compared to the voxel grid and a much larger factor resulted in a premature stop.

Fig. 1. Aneurysm.



Shifting of the neck is stopped when an aneurysm voxel is encountered between the two bounding planes of the current slice but outside the cylinder, face connected to a vessel voxel of this slice, possibly via a chain of face connected vessel voxels. If not, the aneurysm voxels of the current slice are changed to "normal" vessel voxels.

After the neck has been shifted, the graph structure is adjusted. If the neck node has exactly one branch, the shift path is used to extend this branch. The neck node is moved to the last knot of this extended branch. If a neck node has more than one branch, a new neck node is created, connected to the old neck node via the shift path.

5 Results and Discussion

We have applied the method to improve the accuracy of the estimated aneurysm volume by shifting of the aneurysm necks to 42 clinical volumes with an aneurysm

(11 of them 256x256x256, the rest 128x128x128), acquired with the 3D Integris system [8]. In 36 of these cases aneurysm voxels were changed to "normal" vessel voxels. The mean number of aneurysm voxels changed is 3.5% of the number of aneurysm voxels, the maximum number is 16.7%. The total numbers of necks is 131, the total number of run-up regions cleaned is 72, the total number of necks shifted is 43. Not a single neck was moved inside the real aneurysm. The effect of a shifted neck can be perceived by comparing Fig. 1.3 with Fig. 1.4.

Shifting of the erroneous aneurysm necks to the real aneurysm gives better estimates for our clinical aneurysm volumes. Possibly more important than these better estimates is that a picture without a lot of erroneously labelled "normal" vessel parts (compare Fig. 1.3 with Fig. 1.4) increases the confidence in the accuracy of the aneurysm labelling method.

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