Local Distance Thresholds 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. If the aneurysm volume is known, a physician may treat an aneurysm by filling it with coils or glue. We presented a fully-automatic aneurysm labelling method to compute this volume in a previous paper. The global distance thresholds of this method may result in an estimated aneurysm volume which is too large. We developed a method to derive local distance thresholds from the segmented vasculature. Application of these thresholds 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, a local widening of a vessel (see Fig. 1.1).

Physicians may treat an aneurysm by filling it either with coils or glue. 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. 1.3).

Two global distance thresholds derived from the segmented vasculature (see Fig. 1.2) are used in this method. The *center threshold* is used to label the center voxels of the aneurysm, the *shell threshold* to label the voxels in the shell around the center part of the aneurysm. As explained in [2], in case of a spherical aneurysm the shell threshold should be equal to the center threshold.

In case of an elongated aneurysm we need a shell threshold greater than the center threshold to label the voxels in the far ends of this aneurysm. However, if a "normal" vessel part is connected to the short side of an elongated aneurysm, the vessel voxels at the start of such a "normal" vessel part will be labelled as aneurysm voxels because their distance to the center part of the aneurysm is less than this larger shell threshold. In this case the estimated aneurysm volume is too large. This larger threshold may also give errors for an almost spherical aneurysm as shown in Fig. 1.5 (the cross indicates the center of the aneurysm).

The problem is to label the vessel voxels in the far ends of an elongated aneurysm (requires a large shell threshold) without labelling the vessel voxels in the “normal” vessel parts connected to the short sides (requires a small shell threshold).

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 derive fully-automatically local distance thresholds from the segmented vasculature. These thresholds represent a *tight bounding surface* around the aneurysm. This tight bounding surface is located just outside the aneurysm where it borders on tissue. Elsewhere it intersects the “normal” vessel parts as close to the aneurysm as possible.

4 Method

We use a few hundred rays, starting at the center of the aneurysm, going in all directions, to create the tight bounding surface. The normalized directions of these rays have been computed beforehand from an uniform triangulation of the unit sphere (see Fig. 1.4). The vectors from the center of the unit sphere to the triangle vertices give the normalized directions for the rays. Each vertex (ray) shares a number of triangles with other vertices (rays). These neighbor relations are also available.

For each ray a threshold is computed. This threshold defines a spherical surface section such that vessel voxels closer to this ray than to any other ray with a distance to the aneurysm center greater than this threshold are never classified as shell aneurysm voxels. The union of the spherical surface sections is our tight bounding surface.

Because the border vessel voxels (i.e. vessel voxels with at least one tissue voxel as neighbor) define the vessel surface completely, the border vessel voxels of the aneurysm are selected (how is explained in the sequel) to compute the thresholds.

The threshold of a ray of the tight bounding surface is computed from the distances to the aneurysm center of the selected border vessel voxels which are close enough to this ray. This threshold is equal to the weighted average of the distances of these border vessel voxels plus 2.3265 times the weighted standard deviation of these distances. The weights are derived from the gaps between the selected border vessel voxels and the ray. The factor 2.3265 corresponds in case of a Gaussian distribution to a probability of 1%.

The threshold of a ray without border vessel voxels is computed from its neighbor rays. If all its neighbor rays have also no border vessel voxels, the threshold of the closest ray with border vessel voxels is used.

Selection of the Border Vessel Voxels. Because the border vessel voxels of an aneurysm have normally a gray value gradient vector in the direction of the aneurysm center, only border vessel voxels for which the angle between this direction and the gradient vector is small enough (the *"convergent border vessel voxels"*) are selected.

But, a "normal" vessel part may also have convergent border vessel voxels. To exclude these convergent border vessel voxels, we create a blocking surface between the aneurysm and these border vessel voxels. For each blocking ray a threshold is computed. This threshold defines a spherical surface section such that convergent border vessel voxels closer to this blocking ray than to any other blocking ray with a distance to the aneurysm center greater than this threshold are never used for the tight bounding surface.

Because the side of a "normal" vessel part, closer to the aneurysm center, will have border vessel voxels with a gradient vector pointing away from the aneurysm center (the *"divergent border vessel voxels"*), these divergent border vessel voxels are used to create this blocking surface. The threshold of a blocking ray is equal to the weighted average of the distances of the divergent border vessel voxels which are close enough to this ray. The weights are derived from the gaps between these divergent border vessel voxels and the ray. The threshold of a blocking ray without enough (explained in the next paragraph) divergent border vessel voxels is set to a value greater than the greatest distance in the volume (implies no blocking by this ray).

Due to noise divergent border vessel voxels may be present on the aneurysm surface. To eliminate the influence of these sporadic erroneous border vessel voxels, a minimum number of divergent border vessel voxels is required for a blocking ray. This minimum number depends on the total number of voxels of the volume.

5 Results

To assess the local distance thresholds of the tight bounding surface, we used twenty-eight clinical aneurysm volumes (nine of them 256x256x256, the rest

128x128x128), acquired with the 3D Integris system [6]. The accuracy of the estimated aneurysm volumes was improved on average by 1.5%. For the segmented vasculature shown in Fig. 1.2, the result after iso-surface generation is shown in Fig. 1.5 if the aneurysm is labelled using the global shell threshold, and in Fig. 1.6 if the aneurysm is labelled using local distance thresholds. For this case the accuracy of the estimated aneurysm volume was improved by 6.0%.

6 Discussion

Using local distance thresholds instead of the global shell threshold gives better estimates for our clinical aneurysm volumes.

Possibly more important than these better estimates is the reduction of the erroneously labelled “normal” vessel parts in the pictures (compare Fig. 1.5 with Fig. 1.6). Indeed, a picture with a lot of “normal” vessel parts labelled as aneurysm increases the doubts about the accuracy of the aneurysm labelling method.

The tight bounding surface and the blocking surface, both defined on the same 3D ray star, offer an useful tool to include additional information about the boundary between the aneurysm and the connected “normal” vessel parts. We are currently developing algorithms to extract this kind of information from local shape properties.

In case of an aneurysm with a narrowing, the tight bounding surface may prevent labelling of the outer region behind the tissue gap. We detect this kind of regions after which cumulative labelling is applied. A tight bounding surface is created for each such region after which the vessel voxels inside this tight bounding surface are labelled as aneurysm voxels.

References

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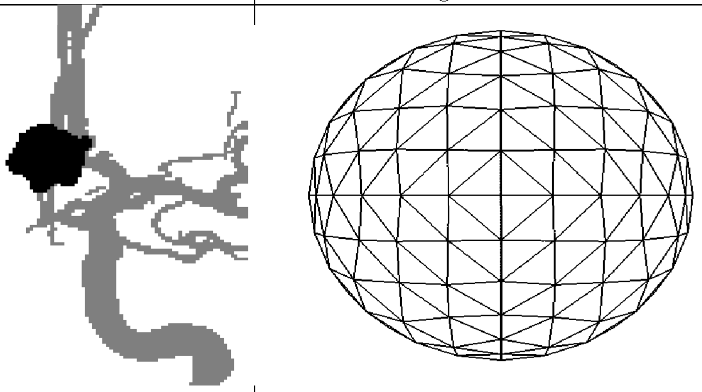
Fig. 1.

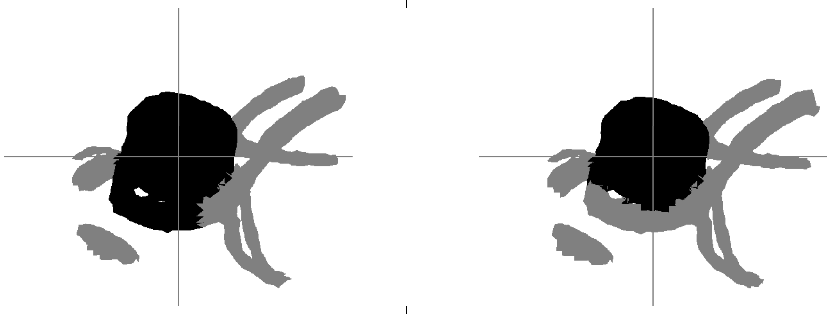
1: Gray value volume

2: Segmented volume



3: Labelled volume

4: Ray sphere



5: Aneurysm by the global shell threshold

6: Aneurysm by the local distance thresholds