Fully-Automatic Labelling of Aneurysm Voxels for Volume Estimation

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Abstract. Nowadays, it is possible to acquire volume representations of the brain with a clear distinction in gray values between tissue and vessel voxels. These volume representations are very suitable for diagnosing an aneurysm, a local omnidirectional widening of a vessel. A physician can cure an aneurysm by filling it either with coils or glue. So, he/she needs to know the volume of the aneurysm. Therefore, we developed a fully-automatic aneurysm labelling method. The labelled aneurysm voxels are used to compute the volume of the aneurysm.

1 Problem

Nowadays, it is possible to acquire volume representations of the brain with a clear distinction in gray values between tissue and vessel voxels [1]. These volume representations are very suitable for diagnosing an aneurysm, a local omnidirectional widening of a vessel (see Fig. 1.1).

A physician can cure an aneurysm by filling it either with coils or glue. Therefore, he/she needs to know the volume of the aneurysm. The problem is to compute the volume of the aneurysm from the voxel representation.

2 Related Work

Meijering measures the diameter of a phantom aneurysm by positioning a plane. The intersection of this plane with the volume gives a 2D image. After selection of a profile through the center of the projected aneurysm, the diameter is computed on the basis of a gray-value threshold (Chapter 5 of [2]).

Juhan et al. [3] propose methods, tailored to the segmentation of an abdominal aortic aneurysm. They don't subdivide the segmentation in "'normal"' vessel and aneurysm voxels.

Users of the 3D Integris system [4] measure the volume of an aneurysm by positioning a bounding ellipsoid after which the system counts the number of vessel voxels inside this ellipsoid. A small ellipsoid is accurate but difficult to position, a large ellipsoid is easy to position but inaccurate. The accuracy may be improved by removing vessel voxels outside the aneurysm by a cutting tool before the ellipsoid is applied. This laborious procedure gives varying results when applied by different people.

3 What is new

To improve the accuracy and to eliminate the time-consuming interaction and the inter- and intra-operator variations, we developed the first (to the best of our knowledge) fully-automatic aneurysm labelling method.

Our starting point (our algorithms for fully-automatic segmentation will be discussed in a future paper) is a segmented volume with a 0 for tissue and a 1 for vessel voxels (see Fig. 1.1).

We use two Manhattan distance transforms [5]. The primary transform is used to find the center aneurysm voxels, the secondary to find the remaining aneurysm voxels.

The result of our algorithm is a segmented volume in which the "normal" vessel voxels have label 1 and the aneurysm voxels label 2. An example of a labelled segmented volume is shown in Fig. 1.2.

We introduce the basic precondition for the fully-automatic aneurysm labelling method in Section 4.1. The algorithm for labelling of a spherical aneurysm will be explained in Section 4.2. We describe how the labelling algorithm can be extended to deal with aspherical aneurysms in Section 4.3. In Section 5, we present our results. Finally, we conclude with the discussion in Section 6.

4 Method

4.1 Basic Precondition

An aneurysm is a local omnidirectional widening of a vessel (see Fig. 1.1). Therefore, the fully-automatic aneurysm labelling method is based on the following hypothesis:

The maximum of the primary distance transform of the aneurysm voxels is greater than the maximum of the primary distance transform of the vessel voxels in the connected vessels.

This primary distance transform (abbreviated to PDT) is the Manhattan distance transform with regard to the vessel boundaries.

4.2 Labelling of a Spherical Aneurysm

After the PDT has been computed, the following algorithm is used for labelling the aneurysm voxels:

1. Classify all vessel voxels with a PDT greater than or equal to a certain (so-called inclusion) threshold as center aneurysm voxels.
   This threshold (our algorithm for fully-automatic selection of this threshold is not discussed in this paper) must be greater than the maximum PDT in the connected vessels and less than or equal to the maximum PDT of the aneurysm.

2. Compute the secondary distance transform (abbreviated to SDT). The SDT is the Manhattan distance transform with regard to the center aneurysm voxels.
3. Classify all vessel voxels with a SDT less than or equal to the inclusion threshold as shell aneurysm voxels.
   This pass adds a shell with thickness equal to the inclusion threshold.

4.3 Aspherical Aneurysms

The procedure described in Section 4.2 gives correct results in case of a spherical aneurysm. But in case of for example a spherical aneurysm with a local bulge, the aneurysm voxels in this bulge will not be labelled because their SDT is greater than the inclusion threshold.

We can, however, discriminate between the voxels in the connected vessels and those in a local bulge. After all, the connected vessels end on a volume boundary. Therefore, the following procedure is applied after the shell aneurysm voxels have been labelled:

The vessel voxels, face connected to a vessel voxel in a volume boundary slice, possible via a chain of face connected vessel voxels, are removed by a similar twin wave algorithm as used in Section 3.3 of [6].

Note that this step will give erroneous results if the bulge itself ends on a volume boundary.

After the voxels in the connected vessels have been removed, the remaining vessels voxels are labelled as bulge aneurysm voxels.

Remarks:

1. Center, shell and bulge aneurysm voxels get all the same label, namely 2. The different names for the aneurysm voxels are only used to ease the description of the method.
2. In some cases, vessels, connected to an aneurysm, do not end on a volume boundary (for example because of erroneous segmentation). This kind of vessel parts should not be classified as bulges. Therefore, vessel voxels, face connected to a voxel with a SDT greater than the maximum allowed bulge length, possible via a chain of face connected vessel voxels, are also removed. This maximum allowed bulge length determines whether a bulge is classified as an aneurysm part or as a short vessel part.

5 Results

Four aneurysm volumes (128x128x128) with very different characteristics, acquired with the 3D Integris system [4], have been tested. Labelling of the aneurysm takes between 5 and 10 seconds on a SGI Octane. The labelled aneurysms after iso-surface generation are shown in Fig. 1.3, 1.4, 1.5 and 1.6. The aneurysm surface is painted black. Note that in the last example in Fig. 1.6, the labelling

is done on a sub-volume because the maximum PDT in the fat vessel at the bottom is greater than the maximum PDT of the aneurysm.

The total number of aneurysm voxels is used to compute the volume of the aneurysm. This volume may be used as an indicator for the amount of glue needed for filling the aneurysm.

The fully-automatic aneurysm labelling method gives visually acceptable results, both for spherical and aspherical aneurysms, but a clinical validation has yet to be done.

In some cases the boundary between the labelled aneurysm voxels and the vessel voxels differs from the boundary indicated by medical experts. We are currently developing algorithms to refine the boundary.

6 Discussion

The following conclusions can be drawn from the results, the pictures and the experiences gathered during testing:

1. The fully-automatic aneurysm labelling method cannot be used to *detect* an aneurysm because in case of a volume without an aneurysm some of the vessel voxels, connected to the vessel voxel with the maximum PDT, will then be labelled as aneurysm voxels.
2. If one of the vessels in the volume is wider than the aneurysm itself, thereby violating the basic precondition (Section 4.1), the aneurysm can still be labelled if and only if the wide vessel part can be excluded, for example by a volume bounding box.
3. In case of a partially thrombosed aneurysm, only the aneurysm voxels with sufficient contrast agent will be labelled as such because the other aneurysm voxels will be classified already as tissue voxels by the segmentation algorithms.

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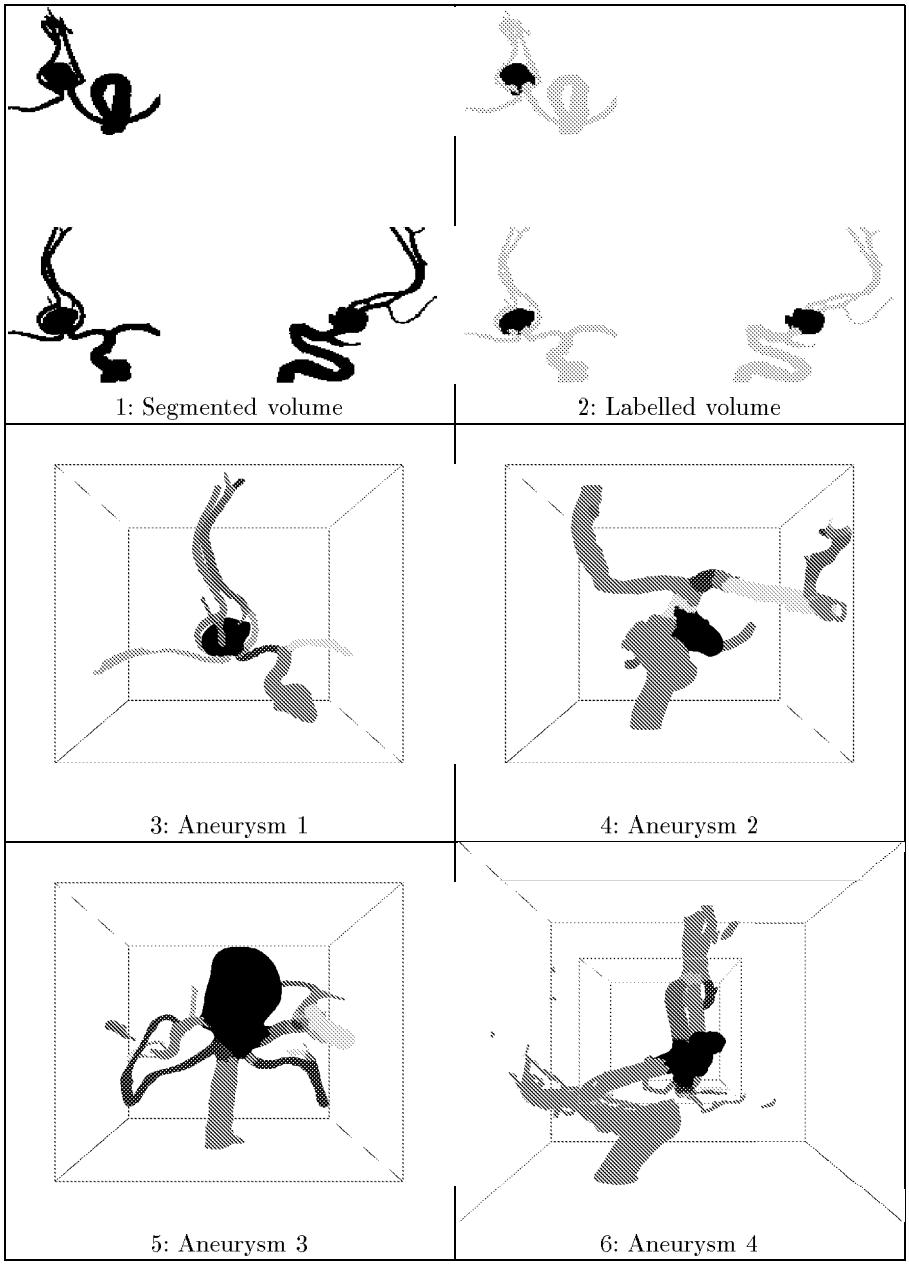

Fig. 1. Aneurysms