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Methods of intracerebral vascular display

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## Methods of intracerebral vascular display

## **SUMMARY**

We are developing imaging methods for better visualization of 3D vascular anatomy. Features

include: 1) Noise-free display of vessels extracted from 3D datasets,

2) Tree-based display, and

3) Reconstruction of angiographic data, with preliminary work successfully reconstructing aneurysms from angiograms.

Fast, interactive display methods permit real-time manipulation of viewing orientation.

**Key words:** computer, MRA, cerebral vessels, segmentation, registration, aneurysm, image analysis

It is essential for the vascular neurosurgeon to visualize intracranial vessels in three dimensions (3D). Unfortunately, there is no ideal imaging modality. MRA and CTA are noisy and may exclude critical data, including small but surgically important vessels, up to 15% of aneurysms, and portions of arteriovenous malformations (1-4). Projection angiography provides more surgically relevant information, but overlapping vessel projections are difficult to visualize in 3D. We are therefore developing new methods of vascular display to help surgeons better visualize complex vascular anatomy. Features include

- 1) Vessels extracted from MRA or CTA datasets to provide noise-free projection images,
- 2) Tree-based display methods to permit highlighting or exclusion of subtrees, and
- 3) Reconstruction of angiographic data into 3D to add vascular information missing from MRA or CTA. Preliminary development of such methods allows reconstruction of aneurysms from angiographic data, with insertion of the aneurysm into a set of extracted MRA vessels.

## **METHODS**

Time-of-flight, 3D MRA was performed in a 1.5T unit with 10mT/m and repetition time/echo time/excitations of 38/7/1. Voxel size was 0.06 x 0.06 x 0.1 cm. AP, lateral and oblique angiograms were also obtained. Images were digitized by laser scanner and showed an anterior communicating aneurysm.

### **Segmentation of MRA data**

MRA segmentation was performed by core methodology, a new approach to image analysis (5,6). Given a user-supplied seed point and an estimate of object width, core analysis automatically extracts an object from even noisy 2- or 3D medical images. MRA datasets are displayed in slices. The user identifies a point within a vessel by mouse click, and the 3D vessel is then automatically extracted at sub-voxel resolution. Vessels often contain hundreds of points

and course through multiple sections. It takes approximately 25 minutes to extract 110 vessels on a DEC 5000/200. No precomputation is required (Aylward, presented at IEEE-WMMBIA 1996).

Segmentation accuracy was tested by simultaneously displaying the original MRA with the set of segmented vessels using a program that displays two fused images in different colors and from any interactively selected angle. Spurious or missing vessels could thus be identified.

### **Tree creation from segmented MRA vessels**

Tree creation is performed by a post-processing program that takes segmented vessels as input. Vessels are displayed in 3 windows as AP, lateral, and axial projections and can be viewed from any user selected angle in a 4th. The user can pick any number of vessel roots. The program then generates vessel trees automatically from these roots by iteratively selecting the orphan with an endpoint the shortest 3D distance from any vessel already part of a tree. The orphan connects to this closest available point, becoming part of the tree. The process terminates when no orphans remain or when a preset maximum jump distance exceeds that required by all remaining orphans. Each vessel keeps a list of its children. A subtree from a given vessel is determined recursively so that, during display, a user selected vessel and all of its descendants can be painted in a distinctive color or not shown.

### **Reconstruction of angiographic data**

Traditional 3D imaging techniques omit important vessels. It would therefore be useful to reconstruct angiographic data into 3D. We have described a multi-step process of reconstructing angiograms that includes: a) Segmentation of MRA and angiographic data, b) Registration (alignment) of an MRA with each of pair of angiographic images, and c) Reconstruction of uncorrelated angiographic data into 3D, using the extracted MRA vessels to provide an initial set of parent vessels upon which to build reconstructed angiographic data (7).

MRA segmentation methods are described above. 2D images are segmented by a similar point and click method (8). We have also developed a core-based 3D-2D registration method that uses vessels as a registration basis. Hundreds of vessel points at subvoxel and subpixel resolution are used during registration, making this method more accurate than traditional methods based upon a small number of fiducial markers (Liu, submitted).

We have also described methods of automatic curve- and pixel-pairing to reconstruct 3D curves and have reconstructed a middle cerebral tree in phantom data (7). Fast algorithms providing high spatial resolution are available (Bullitt, submitted). We have not corrected for MR distortion and so have not attempted wide-volume reconstruction requiring global registration. As aneurysms can be recognized on both views, however, only local registration is required.

For this report, MRA vessels were extracted adjacent to but not including the aneurysm. Vessels were registered with all 3 angiographic views, providing local registration in the aneurysmal region. The aneurysm was extracted from each 2D image and reconstructed 3 times, using all 3 image pairs. If the aneurysm neck can be seen on 2 views it can be reconstructed as a separate vessel. In this case the neck was only visible on one view. The reconstruction process includes automatic connection to a 3D parent vessel, however, thus providing a reasonable approximation of the neck even if the neck cannot be defined on two views. In this case, the aneurysm was reconstructed from the angiographic data alone; the neck was defined by automatic connection of the aneurysm to its parent vessel. The program automatically calculates the width of a reconstructed vessel from its 3D spatial location and its width on projection views.

Reconstruction accuracy was tested by comparison of the coordinates of reconstructed and segmented aneurysms. Comparison was also made of projections of the reconstructed aneurysm and aneurysm neck to the 3 angiographic images and to projections of MRA data..

### **Display**

For the surgeon, segmented and reconstructed vessels are displayed using a Silicon Graphics RealityEngine, permitting the user to change the point of view in real time. A number of display options are available. A wireframe model of the ventricular system aids orientation.

### **RESULTS**

Figure 1 shows the MRA dataset and a full set of segmented vessels from the same projection angles. The segmented dataset is noiseless and contains over 90% of the MRA vessels. No spurious creations were found when the set of extracted vessels was compared to the MRA.

Figure 2 shows the vessels in Fig. 1 in a tree-based display. A tree is highlighted in blue and a branch in red in the upper 4 frames. Highlighted structures are easily recognized from any angle. Below, the user has requested omission of the previously highlighted tree from display. Omissions can be used to remove veins from CTA data or to prevent obscuration.

When the reconstructed aneurysm was compared to the segmented aneurysm, the center of the reconstructed aneurysm lay in the same voxel in one case and in an adjacent voxel in the other 2 cases. Superimposition of projection views showed excellent agreement of the reconstructed aneurysm with both MRA and angiographic data. The reconstructed neck had the thickness of the parent vessel but was otherwise correct. Figure 3 shows one of the reconstructed aneurysms together with the adjacent, segmented vessels in our surgical display tool. The final frame shows these vessels from a likely angle of surgical approach.

## **DISCUSSION**

Our intent is to create a vascular display program that can be used both for preoperative planning and intraoperative guidance. There are several advantages to our methods. First, segmented and reconstructed vessels can be shown without the noise of MRA or the veins and bone seen by CTA. Second, tree-based displays can highlight any vessel or subtree or can remove vessels or subtrees from display. Highlighting is useful for anatomical teaching or to separate arteries from veins in AVM planning. Subtree omission prevents obscuration of areas of interest. Tree creation is not possible without using segmented or reconstructed data.

The final display permits the user to interactively change the point of view in real time. The surgeon therefore can inspect an aneurysm and surrounding vessels without obscuration and from any angle including that of surgical approach, so as to quickly visualize the relevant anatomy (Fig 3). Our goal is to additionally include the 3D reconstruction of vessels important to surgical planning but seen only by angiography. No other method permits such visualization.

This report describes progress toward these goals, including segmentation of over 90% of MRA data (Fig 1), tree creation including even the most peripheral branches (Fig 2), and reconstruction of aneurysms from angiograms (Fig 3). This last ability is already of clinical utility when aneurysms cannot be seen by traditional 3D acquisition techniques. The final display program employs a high-level workstation. All other modules run well on standard workstations.

Development is still required in a number of areas, including width determination, stop conditions during object extraction, correction of MR distortions, testing of reconstruction methods, and incorporation of multiple separate programs into a coherent whole. Nevertheless, our current abilities provide significant advantages over traditional methods of vascular display.

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## FIGURE LEGENDS

**Figure 1:** Projection of an MRA dataset (left) and of a set of segmented vessels (right) from similar angles of view. The MRA has been intensity windowed so as best to show the vessels. There is much background noise. Although different settings can reduce noise, holes will appear in some vessels and other vessels will disappear. Segmented vessels were tiled with triangles and surface rendered with Gouraud shading. The display is noiseless and contains over 90% of the MRA vessels.

**Figure 2:** Capabilities of tree-based display. 4 different views are shown simultaneously. Automatic tree creation has been performed using both M1 segments and both posterior cerebral arteries as roots. In the upper sequence, the user has requested highlighting of the tree associated with one M1 segment (blue) and a contralateral middle cerebral branch (red). Below, the user has requested non-display of the M1 tree.

**Figure 3:** Reconstructed aneurysm added to a set of segmented vessels as seen from several angles of view. The tree-creation and branch selection program was used to include only those vessels likely to be seen during an operative approach. The user can alter the viewing position at will and in real time so as to best study vascular relationships. The lower right frame shows the vasculature from the perspective of a likely operative approach.