Visualization and Analysis of Cerebral Arteriovenous Malformation combining 3D and 4D MR Image Sequences

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Abstract. In this paper methods for visualization and analysis of cerebral arteriovenous malformations (AVM) are presented. Spatiotemporal 4D magnetic resonance angiography (MRA) image datasets and 3D MRA datasets with high spatial resolution were acquired for analyzing AVMs. One of the main tasks is the combination of the information of these 3D and 4D MRA image sequences. Initially, in the 3D MRA dataset the vessel system is segmented and a 3D surface model is generated. Then, in 4D MRA image sequences the temporal intensity curves are analyzed voxelwise and the time point of blood inflow is calculated. These parameters are saved as a 3D dataset representing the dynamic characteristic. After an affine 3D-3D registration of both MRA datasets the color-coded visualization of the temporal information in slice and surface model view with high local resolution becomes possible. The combined visualization of the individual and complicated anatomical structure and the haemodynamic in 3D supports the visual evaluation of the AVM.

Keywords: magnetic resonance angiography; cerebral arteriovenous malformation; maximum intensity projection; mutual information; image registration;

1. Introduction

Cerebral arteriovenous malformation (AVM) is a congenital disorder of blood vessels within the brain. An AVM builds an abnormal direct connection between the arteries and the veins, without having the normal capillaries between them. Thus, a lack of blood flow in other areas of the brain can occur. Abnormal pressure in the veins increases the risk of a hemorrhagic stroke. Possible treatments of AVMs are endovascular neurosurgery (obliterating vessels with glue), craniotomy, stereotactic radiosurgery, and their combined therapy [1]. Information about localization and quantification of the AVM [2], detection of feeding arteries (Feeders) and draining veins, and the evaluation of the haemodynamics are required for therapy planning. Currently, intravenous digital subtraction angiography (DSA) with high temporal resolution remains one of the standard methods for AVM assessment. Unfortunately, DSA as an invasive procedure has a complication rate of approx. 0.5%. With regard to the monitoring of disease progression, new non-invasive (lower complication rate) imaging techniques like magnetic resonance angiography (MRA) have to be evaluated [3]. In Bullitt [4] the surface models of vessels and a representation of the AVM using volume-rendering techniques are combined to enable the visualization of the complicated structure of the AVM. Temporal (dynamic) information of the blood flow is not included.

In this paper the software system AnToNIa (Analysis Tool for Neuro Imaging Data) is presented, which enables the combined visualization and analysis of AVMs in spatial

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and spatiotemporal MRA datasets. Non-invasive 3D and 4D MRA are co-registered and evaluated qualitatively and quantitatively using new visualization techniques. Here, one of the main tasks is the representation of the temporal haemodynamics on a freemoving 3D model of the vessel system with high spatial resolution. Visualization and analysis of the individual structure of the AVM can support therapy planning and monitoring.

2. Methods

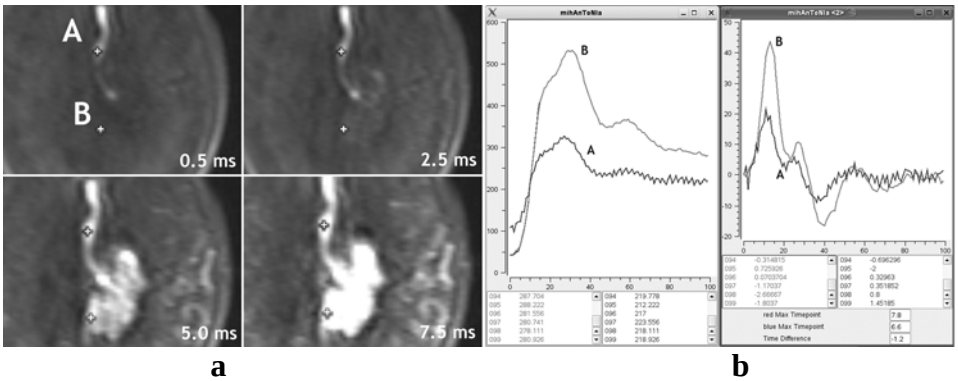
New parallel MRA techniques like GRAPPA (generalized autocalibrating partially parallel acquisition) enable the acquisition of 4D TREAT image sequences (time-resolved echo-shared MR-angiography). These spatiotemporal image datasets are taken as the basis for analyzing haemodynamics. Image quality of 4D TREAT with a time resolution of 0.5 ms and a voxel size of 1.875 mm x 1.875 mm x 5.0 mm is low.
For a detailed segmentation of the vessel system and the quantification of size and location of the AVM structure a 3D TOF MRA (time-of-flight) image sequence with high spatial resolution (0.469mm x 0.469mm x 0.5mm) and a superior blood-to-background-contrast is acquired [5].
The software system AnToNIa enables combined visualization of vessel structures and their haemodynamics as well as the analysis of the AVM kernel and the classification of vessels nearby the kernel. AnToNIa was developed in C++ based on the open insight segmentation and registration toolkit (ITK) and the open visualization toolkit (VTK).

2.1 Segmentation of the vessel system

The vessel system was segmented using thresholding techniques and a region-growing algorithm with subsequent manual correction in the orthogonal views of the 3D TOF MRA. Based on this segmentation a 3D model of the vessel system was generated using the marching cubes algorithm [6].

2.2 Analysis of the haemodynamics

In AnToNIa the borders of the AVM kernel can be defined interactively by setting six orthogonal planes in 3D space. The resulting cuboid is used as a first approximation of the AVM kernel. Evaluation of the vessels in a pre-defined region inside and outside the kernel requires the extraction of haemodynamic parameters.



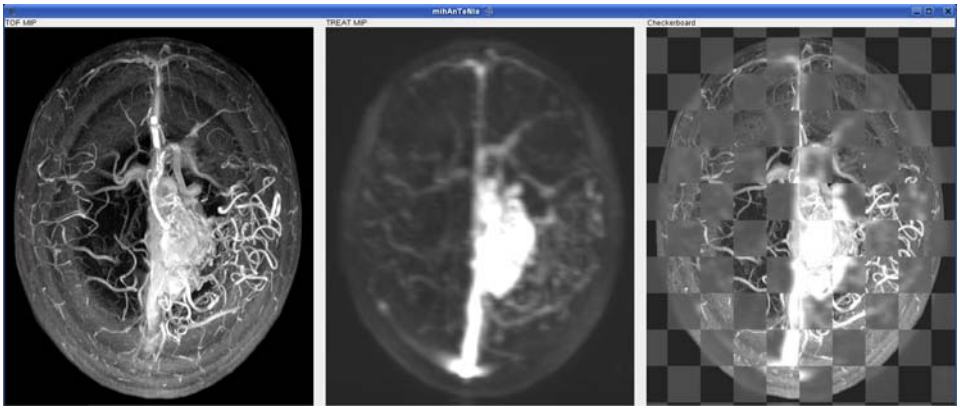
a **b**

Fig.1. Temporal intensity curve and derivation (b) of two voxels in 4D TREAT image sequence (a).

In our approach, the point of blood inflow for each voxel is defined as the time point with maximal derivation of its temporal intensity curve (Fig. 1). Calculating these points reduces the spatiotemporal 4D data volume to a 3D parameter dataset representing the dynamic characteristic of blood inflow.

2.3 Combination of TREAT and TOF image information

Combination of information of haemodynamics based on the voxel-oriented analysis of the temporal intensity curve in TREAT MRA and anatomical vessel structures in high spatial resolution (TOF) requires the co-registration of both datasets. For this purpose a 3D maximum intensity projection over time (MIPt) was created based on the 4D TREAT dataset (Fig. 2, b). This projection leads to an advanced representation of the vessel system in the 3D MIPt including helpful structures to improve the registration result (Fig. 2, c). Thereafter, the resolution of the 3D MIPt was adapted to the TREAT MRA using a cubic resampling filter. Finally, the transformation field between TREAT MRA and MIPt is calculated using an affine 3D-3D registration method with mutual information as similarity measure. Based on the computed transformation field all dynamic characteristics are transferred directly to the TOF MRA image sequence and color-coded visualized depending on the blood inflow characteristic (Fig. 3, a-b). Now, regarding to the anatomical and dynamic information the user can define each vessel as a feeder or a draining vein (Fig. 3, c).



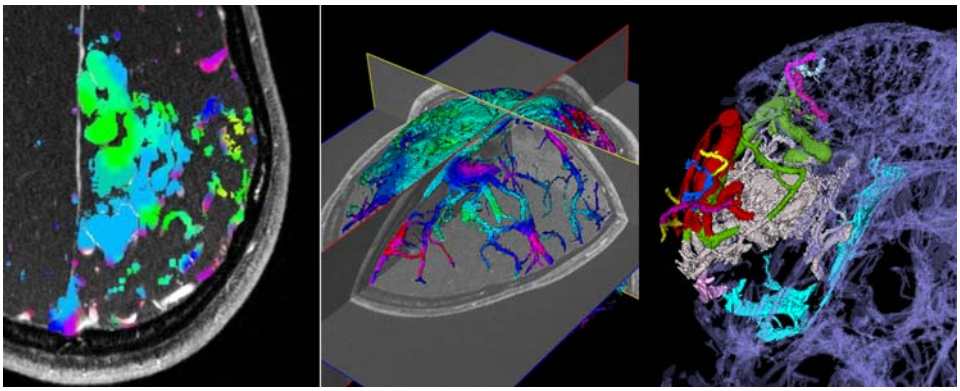
a **b** **c**

Fig. 2: TOF MIP (a) and TREAT MIPt (b) and the registration result in checkerboard view (c).

3. Results

For the development of the analysis and visualization techniques in AnToNIa 12 datasets of patients with AVMs were available. For the evaluation of the first results the vessel system of each patient was segmented and a 3D surface model was generated. Afterwards, the dynamic characteristics were analyzed in 4D TREAT MRA, transferred to TOF MRA based on the 3D-3D registration result, and colorized displayed in 2D TOF slices and on the 3D surface model of the vessel system (Fig. 2).
The combined representation of haemodynamics and anatomical structure in 3D space was useful for diagnosis and therapy planning. Interactive navigation in 3D space,

object rotation, object zooming, and optional crossfade of dynamic characteristics were considered as advantages over DSA.



a **b** **c**

Fig. 3: Colorized visualization of dynamic characteristics in TOF-MRT slices (a), on the 3D model (b), and the colorized classification of vessels near by the AVM kernel (gray) (d).

4. Conclusion

A new approach for visualization and analysis of AVM was presented in this paper. In 4D TREAT MRA haemodynamic parameters were extracted. Co-registration of TREAT MIPt and 3D TOF MRA enables the combined visualization of spatial and temporal information. The extracted parameters can optionally color-coded displayed on 2D TOF MRA slices and on the 3D surface model of the vessel system.

In the near future the segmentation process for the vessel tree should be automated. Also, analysis of the topology of the vessel tree and evaluation of further methods for improved extraction of haemodynamic parameters could enable full automatic detection of feeder and draining veins. In the field of visualization new techniques should be evaluated that enable the real-time visualization of the blood flow in order to replace the static representation by a dynamic one.

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