Computer-aided Arteriovenous Malformation Nidus Segmentation from 3D Time-of-Flight MRA Datasets

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Purpose:

Brain arteriovenous malformations (AVMs) are characterized by locally restricted direct connections of arteries to tortuous veins without interposing capillaries, which are replaced by multiple arteriovenous fistulas. This complex conglomerate is often referred to as the AVM nidus. The missing capillaries cause an increased blood flow in the corresponding veins, which leads to a weakening of the vessel walls and may ultimately result in a rupture. Possible treatment strategies, which aim at preventing such a hemorrhage, include neurosurgical resection, endovascular embolization, radiosurgery, and combination thereof. In any case, detailed knowledge about the location and size of the AVM nidus is required for optimal therapy planning. However, the manual nidus segmentation can be very challenging and time-consuming due to the high nidus complexity. The aim of this work is to present and evaluate a computer-assisted method for the nidus segmentation from time-of-flight (TOF) MRA image sequences.

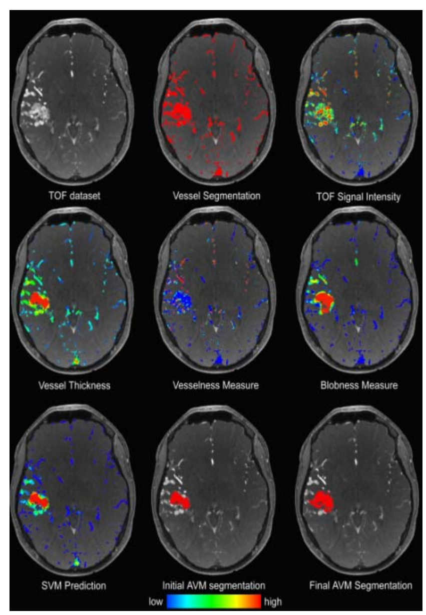
Material and Methods:

The TOF MRA datasets used in this study were acquired using a 3T Trio scanner (Siemens, Erlangen, Germany) after application of contrast agent (~20ml of MultiHance; Bracco Altana Pharma, Konstanz, Germany) applying a multi-slab technique, TR = 36ms, TE = 6ms, flip angle = 25°, an image in-plane resolution of 0.47mm², and 0.5mm slice thickness. These TOF datasets offer a good blood-to-background contrast, which allows a precise delineation of the vessels. Therefore, an automatic level-set approach with anisotropic energy weights [1] was used in this work. The extracted cerebrovascular segmentation serves as the basis for the computer-aided AVM nidus segmentation approach, which is based on four assumptions: (1) the missing capillaries lead to an increased intranidal blood flow and thus to higher TOF intensities, (2) the complete nidus exhibits a larger diameter than normal vessels, (3) the malformed vessels in the AVM nidus exhibit non-tubular shapes, and (4) the compact AVM nidus is represented by an approximated spherical shape.

The vessel diameters at each voxel position were estimated in this work based on the extracted cerebrovascular segmentation using the method proposed by Nyström and Smedby [2]. Furthermore, the generalized vesselness filter [3] was used for enhancing bright tubular and blob-like structures in the 3D TOF MRA image sequence. After this, four feature values are available for each voxel of the cerebrovascular segmentation (TOF signal intensity, vessel diameter, blobness measure and vesselness measure), which are employed for a classification of each voxel of the cerebrovascular segmentation into the nidus or non-nidus vascular structure group using a previously trained support vector machine (SVM) [4]. The voxel-wise classification can be used for generating a new parameter dataset, in which the value representing the distance to the separating SVM hyperplane is assigned to each voxel. More precisely, voxels that are part of the AVM nidus are represented by high positive values in this parameter dataset, which enables a nidus segmentation using 3D volume growing. Due to the fact that the resulting nidus segmentation underestimates the real nidus volume, morphological dilatation and subsequent masking with the cerebrovascular segmentation is performed in a post-processing step.

Experiments and Results:

The proposed method was developed and evaluated based on 15 TOF MRA datasets of patients with an arteriovenous malformation. The AVM nidus was segmented in each TOF MRA dataset by two neuroradiology experts using an interactive drawing tool and the automatically extracted cerebrovascular segmentation as basis. Leave-one-out cross validation was performed for evaluation of the semi-automatically extracted nidus segmentations. Therefore, all datasets except for the actual dataset to be evaluated were used for the voxel-wise training of the support vector machine. Moreover, an OR-combination of the two manually delineated nidus segmentations of each dataset was used for the training. The Dice similarity metric was used for quantitative comparisons of the manual and semi-automatically extracted nidus segmentations. Dice coefficients close to 1 indicate a good consensus while values close to 0 indicate a bad consensus. Overall, the computer-aided method led to nidus segmentation results with a mean Dice coefficient of 0.835 (ranging from 0.731 to 0.968). Compared to this, a mean Dice coefficient of 0.830 (ranging from 0.683 to 0.976) was calculated for the inter-observer nidus segmentation agreement. The manual nidus segmentation required between 5 to 30 minutes of manual interaction depending on the nidus complexity. In contrast to this, the interaction time for the proposed computer-aided nidus segmentation method was below 1 minute.



Conclusions:

In summary, the proposed method enables a fast and reproducible computer-aided segmentation of the AVM nidus from high resolution time-of-flight angiographies within the range of inter-observer variations and may prove beneficial for therapy planning of AVMs.

References: [1] Forkert et al. Methods Inf Med. 2011;50(1):74-83, [2] Nyström and Smedby. SPIE Medical Imaging 2000, pp 515-522, [3] Antiga, Insight Journal 2007, [4] Joachims. Advances in kernel methods 1999.