Automatic Reconstruction of Different Types of Magnetic Resonance Angiograms: Comparison, Evaluation and Reliability

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Abstract

The exact knowledge of the blood vessel geometry plays an important role, not only in clinical applications (stroke diagnosis, detection of stenosis), but also for deeper analysis of functional data, such as fMRI. Here we present a framework to reliably reconstruct the blood vessels from small rodent brains from magnet resonance angiograms (MRA), compare different angiography techniques and present a measure to quantify similarity of different reconstructions.

Since angiograms show blood vessels as spatially closely confined features, they can be used to register MR images of other types (e.g. fMRI) acquired in the same imaging session. This is only possible if MRA delivers reliable, reproducible images and does not show major random distortions. Therefore, we examine the reliability of MRA over subsequent scanning sessions and different imaging methods, both slicewise and three dimensional time-of-flight (2DTOF, 3DTOF) and phase contrast angiography (PC-MRA) with and without the usage of contrast agents (Endorem, Vasovist). Using an appropriate distance measure on our automatically generated geometric vasculature models, we examine the variance between different specimens in order to value the possibility of inter-specimen registration. We further use the rheological information contained in PC-MRA to investigate the reconstructed geometric models with respect to their function by means of fluid dynamics.

Materials and Methods

Rat brain angiograms were imaged using a 4.7 T BRUKER Biospec 47/40 MR scanner, equipped with an actively RF-decoupled coil system. A homogeneous excitation was provided by a whole-body birdcage resonator. A 3 cm head surface coil was used as receiver coil. After dedicated shimming to the imaging volume in order to reduce non-linear image distortions, the angiograms were acquired with either i) a 3DTOF Gradient Echo sequence (field of view 25 x 25 x 25 mm^3, matrix 256 x 256 x 128, TR = 30 ms, TEef = 3.5 ms, flip angle = 45 degree, NEX 4), ii) a 2DTOF gradient echo sequence (field of view 40 x 40 mm^2, matrix 256 x 256, slices: 60, thickness 1.3 mm, TR = 18 ms, TEef = 4.12 ms, flip angle = 60 degree, NEX 4) or iii) a standard PC-MRA sequence (field of view = 35 x 35 x 35 mm^3, matrix size = 256 x 256 x 256, TR = 15.6 ms, TE = 7.3 ms, flip angle = 30°, venc = 40cm/s). On some experiments different contrast agent concentrations (Endorem 0.2 to 0.6 ml/kg) were applied intravenously just before MRA datasets were recorded. The animals were kept under constant Isoflurane anaesthesia via a nose mask. The depth of anaesthesia was adjusted to achieve a stable and physiological respiration rate of the animals (60 bpm). Body temperature was kept constant through heating via a water bath.

All MR angiograms are preprocessed using a self developed algorithm based on a modified homomorphic unsharp masking method to remove RF bias induced by the head coil. After segmenting the vasculature using a two threshold hysteresis, the vessels are thinned out using an Euclidean distance map guided erosion algorithm. The remaining voxel lines and their distance values are used as center lines and radii for a preliminary geometric vascular model based on connected frustums. A last cleanup and smoothing step generates the final model. We developed a measure for the similarity of different reconstructions which calculates the mean distance between the center lines of neighboring frustums, since vertex based measures are prone to positional shifts and depend on comparable vertex densities. For PC-MRA data we visualize the measured flow using a modified streamline code and additionally calculate simulated flow velocity and direction within the reconstructed vessel system constrained by our geometric reconstructions.

Results

The overall reconstruction time for a typical dataset is approximately 3 minutes, achieving a quality at least comparable to human performance. The inspection of 3D TOF scans of the same specimens on subsequent days reveals variances which reside in the range of the scan resolution, no significant distortions are found. Using our distance measure, 3D TOF scans of distinct specimens reveal considerably higher distances, so it is easy to discriminate whether two scans of the same or of different animals are compared. In general the variance between different animals is smaller for the central brain areas. Although PC-MRA and especially 2D TOF methods image a different subset of the whole vasculature, common parts are still well aligned. We show the dependence of imaged vessels on saturation gaps used in 2D TOF measurements, enabling us to discriminate between fast (arteriole) and slow (venule) vessels. Due to turbulent flow, small vessel diameters and measurement errors, the direct calculated streamlines are erroneous. Using the flow simulation of the reconstructed vessel geometry, we are able to depict these areas, which could often be found in front of bifurcations.

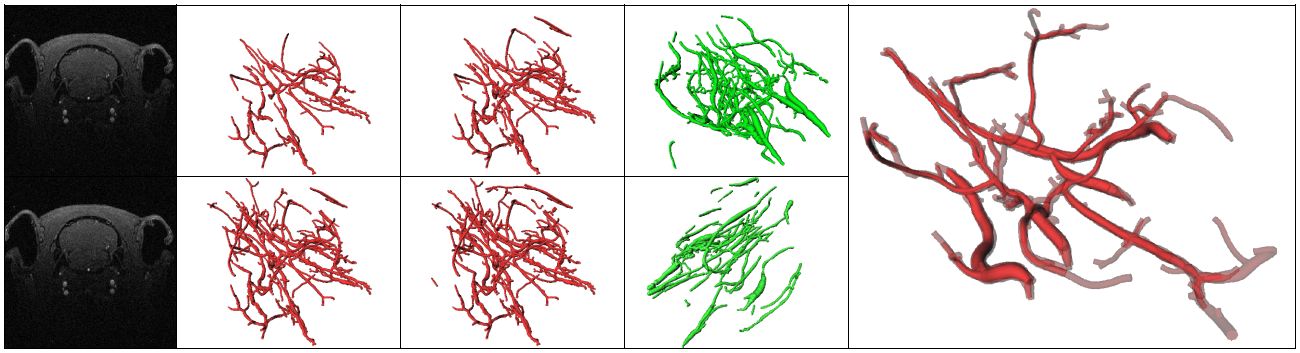

Figure1: [column 2,3] Reconstruction of brain vessels from MRA's of the same rat using 4 different concentrations of endorem (0.0, 0.2, 0.4 and 0.6 ml/kg). [column 4] Reconstruction from a PC-MRA scan (top) and a 2DTOF scan (bottom). [column 5] Reconstructions from 4 3DTOF scans of the same rat, taken on different days, showing their almost perfect match

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