SELECTIVE LABELING OF MOVING SPINS USING PARALLEL 3D SPATIALLY SELECTIVE EXCITATION

Johannes T. Schneider[1,2], Wolfgang Ruhm[1], Sarah R. Herrmann[1], Martin Haas[2], Jürgen Hennig[2], and Peter Ullmann[1]
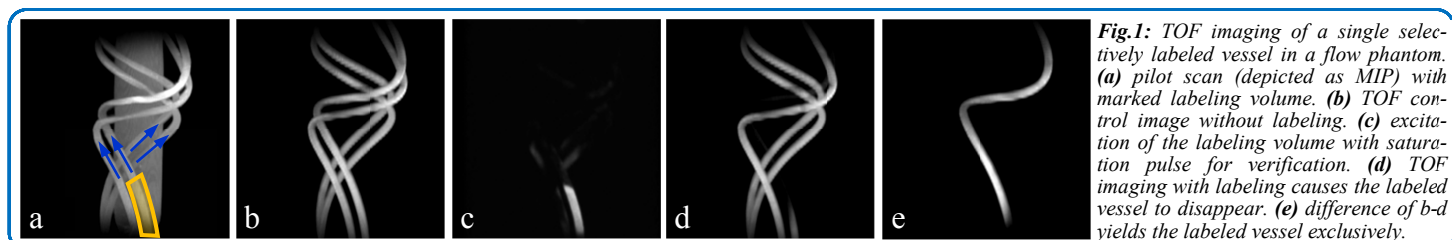
[1]*Bruker BioSpin MRI GmbH, Ettlingen, Germany,* [2]*Department of Radiology, Medical Physics, University Medical Center Freiburg, Freiburg, Germany*

Introduction: In Time-Of-Flight (TOF) angiography [1] signal originating from static tissue is suppressed while signal from flowing blood is enhanced as follows: a 3D volume is covered by multiple thin slices which are imaged sequentially. Using large flip angles for slice-selective excitation and short repetition times, static tissue is saturated. However, blood flowing with a component perpendicular to the imaged slices delivers unsaturated spins resulting in comparatively intense signal and strong contrast. Since all vessels within the imaged stack of slices are highlighted simultaneously, distinguishing one particular vessel from other intersecting and branching ones may be difficult. In order to depict a single vessel separately, this study presents a technique for labeling the spins in one particular vessel utilizing parallel 3D spatially selective excitation (PEX) which allows labeling volumes with high specificity and flexibility.
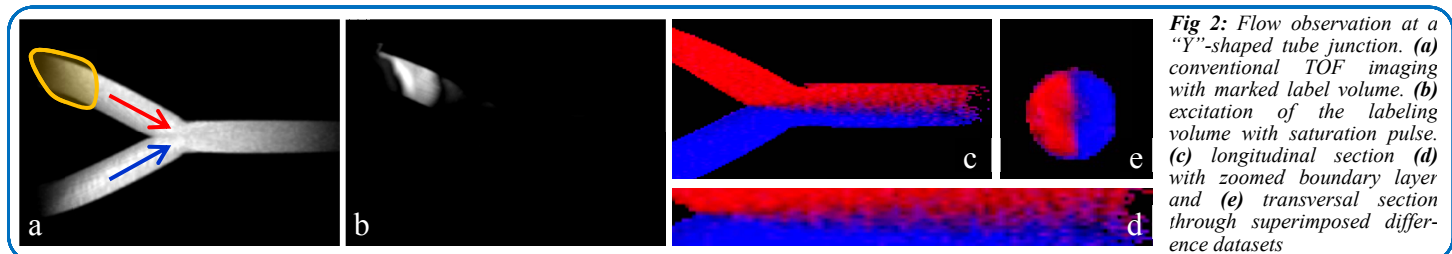
Methods: Similar to arterial spin labeling (ASL) techniques [1], a segment of one vessel is labeled upstream of the imaging volume by means of an additional saturation pulse. For this purpose, 3D PEX is a well suited means, since the saturation volume can be adapted without any significant geometrical restrictions to the spatial course of the particular vessel. By comparing an image acquired with labeling to a reference image from a control experiment without labeling, it is possible to extract the signal originating from the labeled vessel only. As proof of concept, this is demonstrated by a phantom experiment on a Bruker BioSpec 9.4 T system. To this end, 4 separate flexible tubes with flowing water (v = 30 cm/s) were wound around a larger tube containing static water. First, with reference to a pilot scan (a maximum intensity projection (MIP) can be seen in Fig. 1a), the labeling volume was defined. Then, a 3D selective saturation pulse was designed based on a stack-of-spirals transmit k-space trajectory [2]. In order to achieve short pulse durations, 8-channel parallel transmission and 3-fold undersampling of the gradient trajectory were employed which resulted in a duration of 6.0 ms of the 3D selective saturation pulse. Embedded in a conventional gradient echo sequence for TOF imaging, this pulse and a spoiler gradient were applied prior to each slice-selective excitation pulse. For the control experiment, the same sequence was applied the saturation pulse deactivated. After reconstruction the resulting images were subtracted in order to depict the labeled vessel exclusively.

In a second scenario, flow through two entrance tubes that merge to one single exit tube at a "Y"-shaped junction (Fig. 2a) was observed by labeling the water in one of the entrance tubes in front of the junction. Repeating this experiment for the other entrance tube, it is possible to distinguish the spins originating from the two entrance tubes when they are already mixed in the exit tube.

Results: Fig. 1b shows the TOF image of the first flow phantom as acquired in the control experiment without labeling. Signal from static spins is suppressed by the TOF-principle while the spins moving in all 4 tubes provide strong signals. Then, to verify the labeling process, the flow was stopped and a 3D gradient echo experiment was performed applying the designed saturation pulse as the excitation pulse. As Fig. 1c shows, only the spins in desired volume within a single tube, called the labeled tube, are selected. The result of the TOF experiment with labeling can be seen in Fig. 3d where the signal from the labeled tube vanishes and only the flowing spins in the three unlabeled tubes remain visible. Finally, the difference of the image data from the control and labeling experiments (Fig. 3b & d) results in the exclusive display of the spins flowing in the labeled tube, as depicted in Fig 3e. In addition to the pulse verification in Fig. 1c, the perfect cancelation of signals originating from the spins in the unlabeled tubes demonstrates that the labeling pulse has not saturated any other spins outside the labeling volume.

Fig.1: *TOF imaging of a single selectively labeled vessel in a flow phantom.* **(a)** *pilot scan (depicted as MIP) with marked labeling volume.* **(b)** *TOF control image without labeling.* **(c)** *excitation of the labeling volume with saturation pulse for verification.* **(d)** *TOF imaging with labeling causes the labeled vessel to disappear.* **(e)** *difference of b-d yields the labeled vessel exclusively.*

From the experiments of the second scenario, a MIP of the TOF control experiment is shown in Fig. 2a based on which the labeling volume was defined. Again, the labeling process was verified without flow by using the saturation pulse for spatially selective excitation of a short section of one of the entrance tubes, shown in Fig. 2b. The difference between the images of the control and two labeling experiments, one for each entrance tube, yielded the separation of the flow originating from each of the entrance tubes, as visualized in the color coded maps of Fig. 2c-e. The labeling technique allows the observation of the flow paths and of the mixing behavior. In this experiment, the longitudinal (Fig. 2c,d) as well as the transversal (Fig. 2e) sections through the 3D dataset show an essentially laminar and nearly separated flow in the exit tube near the junction while the spins mix more and more with increasing distance from the junction.

Fig 2: *Flow observation at a "Y"-shaped tube junction.* **(a)** *conventional TOF imaging with marked label volume.* **(b)** *excitation of the labeling volume with saturation pulse.* **(c)** *longitudinal section* **(d)** *with zoomed boundary layer and* **(e)** *transversal section through superimposed difference datasets*

Discussion & Outlook: The presented technique of PEX-based spin labeling in TOF imaging extends the benefit of conventional angiography approaches dramatically. Following a single vessel after a branch point or identifying the tissue or functional area that is supplied by a particular vessel may be interesting applications of this technique, e.g. for surgical planning or treatment control. Furthermore, the observation of laminar and turbulent flow is made possible. Alternatives to this PEX-based labeling approach are known from classical ASL techniques where slice-selective spin manipulation or dedicated surface coils are employed for grossly selective saturation or inversion [3]. For labeling the large neck arteries also 2D pencil beam excitation has been proposed [4]. However, the novel approach based on multidimensional spatially selective excitation provides an unprecedented level of flexibility and specificity. Volumes of any shapes and curvilinear vessels can be used for labeling and close proximity of different vessels will no longer render single-vessel labeling unfeasible. Especially for labeling small vessel segments, selectivity is mandatory for all 3 dimensions, which typically results in long durations of the 3D saturation pulses. In such cases, parallel excitation is an optimal means to reduce pulse durations to reasonable values. This is mandatory to achieve short repetition times and sufficient saturation effects on the one hand and to allow neglecting the spin movement during the pulses on the other hand. For this kind of application, the requirements concerning robustness and accurateness of PEX are only moderate compared to other PEX applications like inner-volume imaging because the definition of the labeling volume with very basic shapes and low spatial resolution is sufficient and the saturation process is relatively robust against small PEX imperfections. Therefore, this study presents a representative example of how PEX can surpass the performance of the conventional approaches significantly with only moderate additional effort, thus rendering the presented technique suitable for practical application.

References: [1] Bernstein MA, et al.; Handbook of MRI Pulse Sequences, 2004   [2] Schneider J.T. et al.; ISMRM 2010, 103
[3] van Laar PJ, et al.; Radiology 2008, 246:354   [4] Davis NP, et al.; MRM 2003, 49:1133