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Magnetic resonance imaging of slow flow in plants.

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The functionality of vascular systems in complex plant regions like nodes, which connect stems with lateral organs, remains only partially understood. Spatially resolved slow-flow measurements could provide new insights into flow dynamics in and between vascular bundles and the conductive connections of lateral organs. Traditional methods lack spatial resolution and imaging flow using contrast agents is highly invasive and damaging to the tissue. Promising results in phantoms and in some cases in living plants were demonstrated using pulsed field gradient spin-echo sequences (PFGSE) in magnetic resonance imaging (MRI). However, previous phantoms using flow velocities at 17 mm/s in a 0.4 mm radius tube or 3 mm/s in a 0.35 mm radius tube, demonstrated flow conditions beyond typical plant vasculature. Xylem vessels and flow velocities in plants typically range from 10–200 µm and 1–10 mm/s respectively, depending on environmental conditions.

Our goal was to modify a standard Bruker spin-echo DTI sequence by adding a RARE-module to be able to acquire q-space and measure flow in a spatially resolved manner. For this, we used a Bruker 9.4-T AvanceNeo 400WB vertical bore NMR spectrometer equipped with a Bruker Micro2.5 imaging probe and gradient insert delivering maximally 1467.2 mT/m.

We will present measurements on phantoms, simulating sap flow in plants verifying the robustness and accuracy of our method. Furthermore, we show the first flow measurements on a naturally transpiring shoot of Passiflora quadrangularis. In previous studies, the dynamic displacement propagator for voxels with flow exhibited an asymmetric shoulder on one side of the Gaussian distribution, unlike voxels containing only stationary water. With the improved gradient strength, we can resolve propagators with distinct peaks, separated from the stationary water fraction, that are shifted depending on the flow velocity in each voxel. In addition, we demonstrate that by tailoring the parameters to the existing conditions, the measurement time can be reduced from 3 h 25 min to just 55 s, while still distinguishing between stationary and flowing water on a voxel basis.

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