INTRODUCTION In conventional myelin water imaging (MWI), the myelin water signal, which is characterized by $T_2$ (or $T_2^*$), is acquired based on the $T_2$ (or $T_2^*$) differences among water compartments. Recently, a new approach, Direct Visualization of Short Transverse Relaxation Time Component (ViSTa); previously referred to as background-suppressed MWI (BGM) with exchange by nulling the long $T_1$ signals. This method does not require any ill-conditioned data fitting and, therefore, provides a high quality myelin water image (Fig. 1). It has been demonstrated that the $T_2^*$ of ViSTa is in the range of myelin water (< 25 ms at 3T), suggesting the origin of ViSTa as myelin water. In this work, we explore the phase and magnetization transfer (MT) characteristics of ViSTa to further consolidate the signal origin of ViSTa as myelin water.

BACKGROUND Phase of myelin water: Recently, myelin water has been demonstrated to have distinct phase characteristics from axonal/extracellular water. When the fibers are perpendicular to $B_0$, the myelin water phase shows a large positive frequency shift, but the axonal/extracellular water phase or mean GRE phase shows a small negative frequency shift. To account for this observation, a new model, hollow cylinder model (HCM), has been proposed. MT of myelin water: It has been studied that myelin water shows much larger magnetization transfer ratio (MTR) than that of long $T_2$ signals. Additionally, as the MT pulse shifts away from the excitation RF pulse, myelin water has shown an MTR peak earlier than that of long $T_2$ signals. Hence, if the ViSTa signal originates from myelin water, both the phase evolution and the MT effects of ViSTa are expected to match the characteristics of myelin water.

METHODS Five subjects were scanned for the phase experiment and three for the MT experiment at 3T (IRB-approved). Scan parameters for ViSTa were: 2D single slice (5 mm), TR = 1160 ms, TI/TI/TE/TD = 560/220/380 ms, number of echoes = 32, in-plane resolution = 1.72 x 1.72 mm$^2$ (for phase) or 2.5 x 2.5 mm$^2$ (for MT), and TE = 3 to 78.64 ms (for phase) or 1.72 to 71.16 ms (for MT). GRE sequences with the same parameters were acquired for comparison (both phase and MT). In the phase experiment, DTI was acquired to determine perpendicular and parallel fiber ROIs, and to generate a myelin water phase map from the HCM. The parameters for the HCM were from the susceptibility anisotropy model with exchange in ref 3 (Table 2). To generate phase images from ViSTa and GRE, non-local phase was removed from the HCM. The parameters for the HCM were from the susceptibility anisotropy model with exchange in ref 3 (Table 2). To generate phase images from ViSTa and GRE, non-local phase was removed by RESHARP. The MT pulse parameters were as follows: duration = 20 ms, FA = 2000°, frequency offset = 3 kHz, and MT delays = (the end of MT pulse to the start of the excitation pulse) 11, 40, 70, 120, and 170 ms for ViSTa and GRE, and 250, 400, 600, 800 ms for GRE only. MTR was generated using the first echo.

RESULTS The ViSTa phase image (Fig. 2B) shows a substantially different contrast from the GRE phase image (Fig. 2A). When DTI (Fig. 2C) was used to generate a myelin water phase map using the HCM, it shows remarkable similarity to the ViSTa phase image (Fig. 2B vs. D; red arrows indicate perpendicular fibers and blue arrows indicate parallel fibers). When the fibers were polarized (solid lines in Fig. 3), ViSTa shows a large positive frequency shift in the perpendicular fiber ROI (red). On the other hand, GRE shows a negative frequency shift (blue). In the parallel fiber ROI (18° relative to $B_0$), ViSTa shows a small positive frequency shift (purple) whereas GRE shows almost zero shift (green). These measurements are in accordance with the HCM simulation results (dashed lines), confirming that the phase characteristics of ViSTa are close to those of myelin water. Analysis of the MT data shows a much larger MTR in ViSTa (52.2 ± 13.5 %) than in GRE (7.3 ± 5.4 %). Overall, ViSTa shows a larger MTR at short MT delays (< 170 ms) and an earlier reduction of MTR than GRE (Fig. 5), agreeing with the myelin water MT characteristics.

CONCLUSIONS We demonstrated that the phase and MT characteristics of ViSTa are in accordance with the myelin water characteristics shown in previous studies. These results, in addition to the short $T_2^*$ characteristics of the ViSTa magnitude, support the origin of ViSTa signal as myelin water. Recently, the myelin water phase has shown sensitivity to demyelination. Since ViSTa can provide reliable phase images without ill-conditioned data processing, ViSTa phase may be useful for clinical applications.