Magnetization Transfer in Lamellar Liquid Crystals
Scott D. Swanson¹, and Dariya I. Malyarenko¹
¹Department of Radiology, University of Michigan, Ann Arbor, Michigan, United States

Introduction: Magnetization transfer (MT) is often used in clinical applications of MRI [1] yet a detailed picture of the underlying physics responsible for MT remains cloudy. Appropriate model systems to study MT will clarify molecular mechanisms used in the field help make sense of the MT results collected in vivo [1]. Though some work in membrane systems has been done [2], most MT model systems have been either cross-linked proteins (gelatin or albumin) or polysaccharides (agar, agarose, or starch), which are not representative of MT in vivo.

Mixtures of surfactants, water, and alcohols form well characterized systems [3,4] that mimic many properties of biological membranes. We have found that these lyotropic lamellar liquid crystals (as surrogate membranes) generate MT between the water and lipid phases and allow numerous molecular permutations to help disentangle MT properties. We report here studies of the mole fraction of decanol and weight percent of water influences on MT parameters, such as the estimated solid component (M₀), cross-relaxation rate (Rₓ), and solid component T2 (T₂b), in lamellar liquid crystals composed of sodium dodecyl sulfate (SDS), decanol, and water.

Methods: Based on literature values for lamellar phase [4], known weights of the constituents were added to glass vials. The vials were sealed and then vortexed, centrifuged, heated, cooled, and aged to assure sample uniformity. Care was taken to assure that the samples were in stable regions of the lamellar mesophase [4]. Four samples were made at different weight fractions of water (Cₜ = 65% and 45%) and different mole fractions (m.f.) of decanol to total lipid protons (decanol + SDS) (χₜ = 0.45 and 0.65). Samples were studied at 22 and 40 °C at 2T. CW RF irradiation (10 sec) was applied at 4 RF power levels and 19 off-resonance frequencies. Data was fitted to the standard MT model using a super-Lorentzian line shape [5] and values of MT parameters were estimated (Fig.1 and Table 1).

Results: Rₓ increases as water content decreases, consistent with a decrease in the average water rotational correlation time. Rₓ decreases with increased decanol content or conversely increases with increased SDS content. M₀ increases with decanol content and with increased lipid (SDS + decanol) content. M₀ is discussed at length below. T₂b is relatively constant for all four samples but significantly longer than the 10-15 μs typically observed in vivo.

Discussion: Figure 2 shows that, though M₀ decreases as water content increases, Fig. 3 confirms that M₀ is proportional to the ratio of decanol protons to water protons (additional results from samples at Cₜ = 65% also plotted). In this chemical system, decanol protons are the primary species participating in MT. A marginal increase in M₀ with increasing temperature (not shown), as well as Rₓ decrease with increasing decanol content likely reflects competition with energy preferred water coordination in sodium hydration sphere. The relatively long value of T₂b indicates significant motion within semi-solid part of the liquid crystal. This motion will minimize intermolecular NOE (between decanol and SDS) and quench spin diffusion. This scenario is fortified by MT studies of lamellar samples prepared in D₂O. In the deuterated samples, we easily see the lipid proton NMR signal and find that the lineshape is due to inhomogeneous broadening: off-resonance RF saturation does not uniformly decrease the intensity of the lipid resonance.

Conclusions: Lyotropic liquid samples provide a convenient model to study the molecular properties of MT representative of in vivo systems. The ability to observe the solid-like fraction, control over the water content, control over the molecular constituents and the ability to selectively deuterate individual molecular species will lead to a more complete molecular picture of MT. The composition of biological membranes in vivo may affect the amount of MT generated.