Probing Dimensions of Periodic Microstructures Using Intermolecular Multiple-Quantum Coherences at 1.5 T

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Introduction

The signals resulting from the distant dipolar field generated by the bulk of protons in water can be explained either by the classical demagnetizing field [1] or by intermolecular multiple–quantum coherences (iMQCs) [2]. iMQCs of any order n can be generated by the CRAZED–type pulse sequence [2] shown in fig. 1. The distance of the dipolar–coupled spins which are detected in the experiment is given by the correlation distance $d=\pi/(\gamma G\tau)$, where G=strength and τ=duration of a gradient. It has been shown [3], that for $n\neq 2$ signal formation in periodically structured samples is only expected when the correlation distance d is a linear combination of the characteristic length scale λ_s of the structure: $d=\sum_i l_i\cdot(\lambda_s/2)$; $l=\pm 1,\pm 2,\ldots$. This relation leads to diffraction–like phenomena, which have been observed recently at 4 T [4]. In this study, a (n=2)– and (n=3)– (double–quantum coherence, DQC; triple–quantum coherence, TQC) CRAZED–type pulse sequence was applied to structured phantoms to extract information about the structural dimensions.

Materials and Methods

Experiments were performed on a 1.5–T whole–body scanner (MAGNETOM Vision® Plus; Siemens, Erlangen, Germany). Two capillary phantoms were built: Phantom A consists of approx. 100 glass micro–capillaries (o.d./i.d.=1.0±0.05mm/0.58±0.05mm) tightly packed into a plastic beaker filled with a solution of H_2O+$NiSO_4\cdot 6H_2O$ (1.25g/l). Phantom B consists of glass capillaries (o.d./i.d.=1.25±0.05mm/0.4±0.05mm) tightly packed into a glass beaker filled with the same solvent. Fig. 1 shows the implemented CRAZED–type pulse sequence with two–step phase cycling according to tab. 1. The phantoms were placed such that the capillaries lay perpendicular to $\mathbf{B_0}$, and the correlation distance was varied by incrementing τ. For the DQC measurement τ was varied from 0.4 ms to 3 ms (79 steps), for the TQC measurement from 0.4 ms to 2.5 ms (85 steps). To verify the origin of the signal, experiments were also performed with θ=54° (θ=angle between $\mathbf{B}_0$ and the direction of G). No signals resulting from iMQCs are expected for this value of θ [3]. The echo at $t=\tau+n\tau+TE$ was acquired using a small flexible coil. Postprocessing of the data was done with jMRUI [5]. The FIDs were fitted by a HLSVD [6] algorithm. To avoid stimulated echos during the subsequent measurements, a $\pi/2$ pulse surrounded by spoiler gradients was applied immediately after signal acquisition. Diffraction–like phenomena are expected for $n\neq 2$. An (n=1)–experiment yields a conventional *Hahn* spinecho at $t=2\tau$, which masks the signal resulting from the distant dipolar field (→ single–quantum coherences, SQCs). Therefore, residual SQCs in an DQC experiment were measured by using a (n=2)–sequence and a SQC phase cycle.

Selection of SQCs		
ϕ	+x	–x
φ	+x	+x
Receiver	+x	–x
Selection of TQCs		
ϕ	+x	–x
φ	+x	+x
Receiver	+x	–x

Tab. 1 (right): Two–step phase cycle for selection of SQCs or TQCs.

Fig. 1

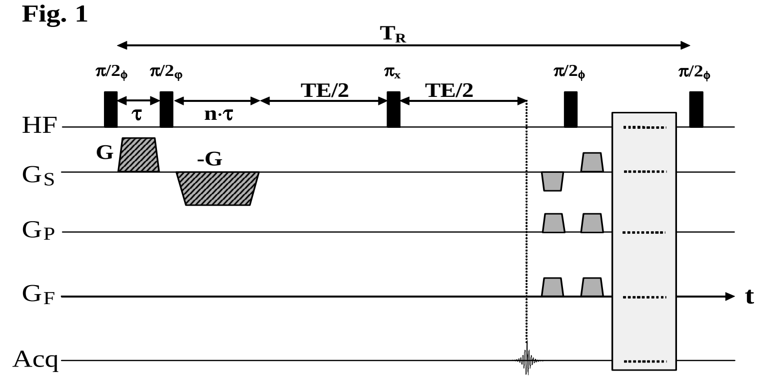


Fig. 1 (left): Pulse sequence. Parameters: T_R=5s, T_E=100ms, NEX=24, Measurement time ≈2h45min (DQC), 3h (TQC). To realize arbitrary values of θ, the coherence–selection gradient (shaded) was split into slice and phase components.

Results and Discussion

The results of the measurements are shown in figs. 2 and 3. Distinct diffraction peaks could be observed in DQC (residual SQCs) and TQC measurements. The correlation times for the dominant diffraction peaks are indicated. The subsequent peaks reflect the possible different linear combinations of the characteristic length scale λ_s of the structure. Great care should be taken when extracting absolute sizes of the structure from these peaks. If the phantom has more than one characteristic lengthscale λ_s, it is possible that the observed peaks reflect superpositions of different λ_s. For θ=54° the peaks vanish as expected [3].

Fig. 2

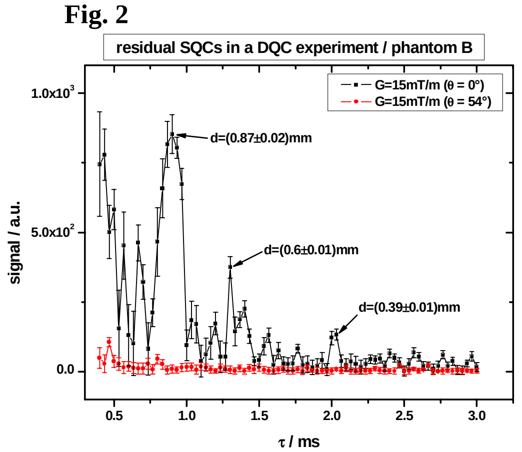
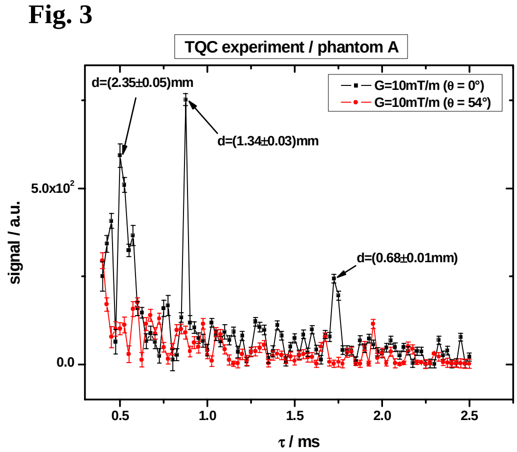


Fig. 3



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