NMR MICROSCOPY WITH ISOTROPIC RESOLUTION DOWN TO 3.0 UM USING DEDICATED HARDWARE

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Introduction NMR microscopy [1-3] has the great potential of providing the plurality of NMR contrast mechanisms also to very small biological samples, such as e.g. single cells. However, at a spatial resolution of a few micrometers it is increasingly difficult to obtain sufficiently high signal-to-noise-ratio (SNR) within a reasonable measurement time. Furthermore, conventional Fourier techniques suffer from loss of true resolution due to diffusion under the encoding field gradients and the associated filter in *k*-space [4]. This effect can be reduced by the use of very strong gradients. However, during frequency-encoding this leads to a decrease of the SNR, favouring purely phase-encoded methods such as constant time imaging (CTI) [5,6]. In this work, imaging with the latter technique is realised with isotropic spatial resolution Δ down to 3.0 µm using RF and gradient coils specifically designed for NMR microscopy. Furthermore, the benefit of high magnetic field B0 is demonstrated.

Methods For high sensitivity, different micro-fabricated planar surface RF coils with a multi-turn spiral with inner and outer diameters ID = 1000 - 20 µm and OD = 1300 - 158 µm were used [7]. The prototype triple-axis gradient was also of planar design with multiple windings and the two planes placed at a distance of 3.3 mm. With the available 60A gradient amplifier the maximum possible gradient strength was 6500 G/cm. RF and gradient coils were mounted on a standard microimaging probehead. Experiments were performed in standard bore magnets with B0 = 7.0 and 18.8 T using a Bruker AVII console equipped with a digital receiver unit (DRU). As a phantom, water doped with $CuSO_4$ ($T_1 \approx 300$ ms) was used and a structure of suitable size was placed close to the coil. Three-dimensional gradient-spoiled CTI was performed with a repetition time of 100 ms and the flip angle set for maximum SNR. According to the spectral width of the NMR signal the receiver bandwidth was set to 300 - 1200 Hz. This was accomplished on the DRU by averaging of the sampled FID values in a corresponding time interval. Isotropic resolution Δ = 16 - 3 µm was realised with gradient strengths suitable to suppress the diffusion effect and approach the theoretically possible resolution of 1.21Δ [8]. For Δ = 3.0 µm a maximum gradient strength of 2444 G/cm was applied for 100 µs on all three axes, leading to a true resolution of 3.66 µm compared to the value of 3.63 µm without diffusion. SNR measurements were executed on the magnitude images with the signal taken in a region-of-interest from the slice of maximum signal and the noise from a signal-free slice.

Results and Discussion Tab. 1 shows parameters and SNR values of selected experiments. With the high sensitivity of the used RF coils already at 7 T Δ = 10 µm can be realised with useful SNR and scan time. However, the same setup at 18.8 T provides far more SNR even at a reduced scan time. With the smallest coil and within a weekend measurement time good SNR could be obtained also for Δ = 3.0 µm. From this data set Fig. 1 shows a slice parallel to the surface coil with a very good delineation of the glass fibres. Tab. 2 summarises the measured SNR (M), normalised with respect to the 1000 µm coil and to the sequence parameters. The SNR shows an approximate linear dependence for decreasing ID. Only the 20 µm coil deviates from this behaviour due to the different relations of ID and OD. The SNR increase for B0 = 18.8 T is in very good agreement with the values calculated using the factor $B0^{7/4}$ (C).

B0 (T)	ID [µm]	Δ [µm]	Scan time [h]	SNR
7.0	200	10	3.6	17
18.8	200	10	1.8	90
18.8	20	3	58.3	45

ID [µm]	SNR 7 T (M)	SNR 18.8 T (M)	SNR 18.8 T (C)
1000	1.0		
500	2.7		
200	5.6	31.6	31.4
100	9.1	55.3	50.9
20		94.2	

Table 1 (above) Parameters and measured SNR for selected CTI experiments.
Table 2 (right) Normalised SNR for different coil diameters and B0.

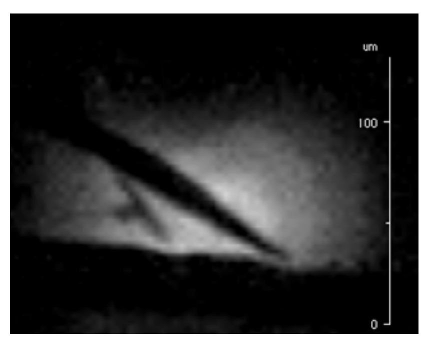

Figure 1 Slice parallel to the 20 µm surface coil taken from a CTI data set with 3.0 µm isotropic resolution showing glass fibres in doped water.

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