Accuracy of q-space derived parameters in MRI - A phantom study of system-induced limitations

J. Lätt[1], D. Topgaard[2], R. Wirestam[1], C. Malmborg[2], O. Söderman[2], F. Ståhlberg[1], S. Brockstedt[1]

[1]Dept. of Medical Radiation Physics, Lund University, Lund, Sweden, [2]Dept. of Physical Chemistry 1, Lund University, Lund, Sweden

Introduction

The aim of this study was to compare the accuracy of parameters derived from q-space measurements between a 3.0 T clinical MRI scanner and a 4.7 T NMR spectrometer. In order to do this, measurements were performed on n-decane, at the two systems using similar pulse sequence parameters.

Materials and Methods

The n-decane is a linear hydrocarbon ($C_{10}H_{22}$) that gives a diffusion coefficient in the same magnitude as *in vivo* cerebral matter [1].
MRI measurements were performed on a 3.0 T Siemens Allegra system. A double refocused SE EPI pulse sequence was used. Diffusion encoding was performed in one direction, given by (x,y,z)=(1,1,1). The temperature was 21°C. NMR measurements were performed on a 4.7 T Bruker DMX 200 MHz spectrometer equipped with a DIFF-25 gradient probe driven by a BAFPA-40 unit, at 20°C using a PGSTE sequence. The diffusion sensitivity was calculated according to the Stejskal-Tanner equation, $b=\gamma^2\delta^2G^2(\Delta-\delta/3)$ where $Td = (\Delta-\delta/3)$ is the diffusion time, δ is the pulse duration, Δ is the time between the two pulses and G is the gradient amplitude. The q-value is defined as, $q=\gamma\delta G/2\pi$ [m^{-1}]. MRI measurements were carried out using 45 different b values, whereas the NMR experiment used 64 different values. The signal decay curves were analyzed after noise correction without any zero filling. Diffusion coefficients (D) and kurtosis [2] were determined from the signal attenuation curve and the full width at half maximum (FWHM) value was determined from the diffusion propagator. Experimental parameters for both systems are summarized in table 1.

Results

In figure 1, signal decay curves from the two systems are shown. The numerical results are summarized in Table 1. The MRI system gives higher D values than the NMR spectrometer for the short diffusion times, but approaches the NMR measurements for increasing diffusion times. The differences can partially be explained by neglected cross terms from the imaging gradients, which for the highest b-values were determined to be within 5 %. The resolution in the q-space measurements is given as $1/q_{max}$, and this will also become the limiting factor for determination of the FWHM value. The limited resolution explains why the measured FWHM values are not in agreement with the expected FWHM, as calculated from the root mean square displacement. Instead the measured FWHM values follow the resolution limits. A similar effect is seen in the kurtosis measurement, where kurtosis values from MRI approached the expected value (k=0) when q-space resolution was increased. This effect was also verified in a simulation (fig. 2) showing the numerical kurtosis values as a function of used maximum q value (resolution limit). However, adding noise to the simulation in order to reproduce a typical MRI measurement, where a signal to noise ratio (SNR) of 30 in the b=0 measurement is representative, gives an unreasonable high kurtosis if the signal is sampled to far out in the q-space.

δ/Td [ms]	6/81		6/91		10/91		10/104		15/104		15/125	
	MRI	NMR	MRI	NMR	MRI	NMR	MRI	NMR	MRI	NMR	MRI	NMR
q_{max} [cm-1]	142	620	142	620	251	602	251	602	388	602	388	602
$b_{max}\times10^9$[s/m^2]	0.7	12.3	0.7	13.8	2.3	13.0	2.6	14.9	6.2	14.9	7.4	17.9
D $\times10^{-9}$ [m^2/s]	1.8	1.3	1.7	1.3	1.6	1.3	1.6	1.3	1.4	1.3	1.5	1.3
Expected [µm]	34	34	37	37	37	37	39	39	39	39	43	43
Resolution[µm]	70	16	70	16	40	17	40	17	26	17	26	17
FWHM [µm]	72	34	73	37	43	37	45	40	39	41	42	44
kurtosis	–0.95	0.12	–0.84	0.08	–0.38	0.08	–0.32	0.03	–0.38	0.07	0.05	0.09

Table 1. Numerical results for n-decane. Given are the maximum q and b-values, calculated D based on b-values between 0–1.0×10^{-9} [m^2/s], expected FWHM, resolution for the displacement distribution, FWHM calculated from the displacement distribution and kurtosis which is calculated from the measured signal curve (MRI after noise correction), for the two systems.

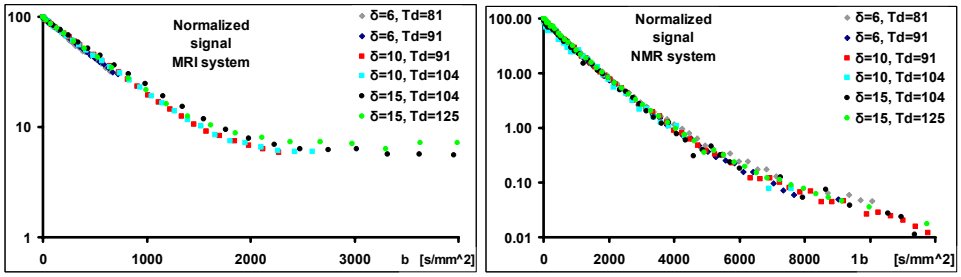

Figure 1: Signal decay curves from n-decane, from the MRI system *(left) and* from the NMR spectrometer (*right*), plotted as a function of q. The signal curves from the MRI system approaches the noise level at low q-values compared to the NMR system.

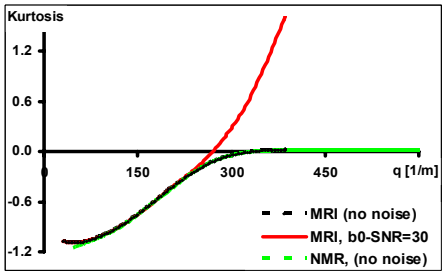

Figure 2: Simulation of kurtosis showing the effects of sampling range. The sequence with δ=15 and Td=125ms were used with D=1.3×10^{-9} [m^2/s].

Discussion

For the simple free diffusion phantom model studied, the measured D and FWHM values differ between the two systems. The differences can be explained by the fact that for the shortest Td, the maximum b-value is to low to achieve enough signal attenuation for accurate D determination and hence, the corresponding maximum q-value is also to low to achieve high enough resolution for accurate determination of FWHM. In the MRI system G_{max} is a limiting factor for achieving high q-values and hence, it will affect q-space derived parameters as well as the minimum resolvable structure. Using shorter pulse lengths and higher gradients, the NMR system was able to accurately estimate FWHM and kurtosis for all the chosen parameter combinations. Our measurements indicate, however, that q-space imaging with optimized sequence parameters δ/Td is feasible at a clinical MRI system.

References

1. P.S. Tofts; MRM 43(2000)
2. Lätt J et al, Proc. ISMRM 11th Meeting, 2003, p 590.