On the reliability of in vitro mapping of ultrashort T_2* of porcine intervertebral discs: a detailed analysis of the signal decay

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Introduction

Relaxation time mapping is a method often used to study degeneration of musculoskeletal tissue [1]. In particular, mapping of ultrashort T_2* with UTE sequences provides high SNR/time and therefore T_2* mapping should be well suited for *in vivo* studies [2,3]. However, the T_2* signal decay is prone to chemical shift and magnetic field inhomogeneities. These physical phenomena can have a strong influence on the shape of the T_2* relaxation decay. The aim of this study was to investigate the reliability of T_2* mapping performed on isolated porcine intervertebral discs (IVD). The T_2* signal decay was pixel-wise fitted by three different analytical functions: a) bi-exponential decay (BIE), b) superposition of a Gaussian decay and an exponential decay (GE) and c) model for two chemically shifted components (2CSC). The choice of the analytical functions was motivated by theoretical considerations which will be given in a forthcoming paper. The match between data and obtained curve fit was estimated by calculating χ^2_{red} maps ("goodness of fit") for all three model functions.

Materials and Methods

Motion segments of fresh porcine lumbar spines were extracted by making two parallel cuts, transverse to the cranial-caudal axis of the spine, through the lumbar vertebrae. Each of the four samples consisted of one intervertebral disc in the middle and half of the adjoined vertebrae L4 and L5 on each side. Spinal processes were trimmed and musculature and soft tissue surrounding the vertebrae were mostly removed. Measurements started directly after sample preparation. Experiments were performed on a 9.4 T small animal scanner (BioSpec 94/20 USR, Bruker BioSpin), equipped with a 1H quadrature resonator with an inner diameter of 7.2 cm operating in Tx/Rx mode. The cranial-caudal axis of the spine segments was oriented along B_0 and axial MR images of the IVD were obtained. T_2* maps were generated by using a standard 2D-UTE sequence (Gaussian excitation pulse, TE_{min} = 0.19 ms, TR = 140 ms, BW = 1.2 kHz/pixel, FOV = 8x8 cm^2, matrix 160 x 160, number of projections = 502, slice thickness = 2mm) with variable acquisition delay t_d = (0 – 30) ms with 52 increments.

Parameter maps were calculated by fitting three different model functions to the measured signal decay in each pixel:

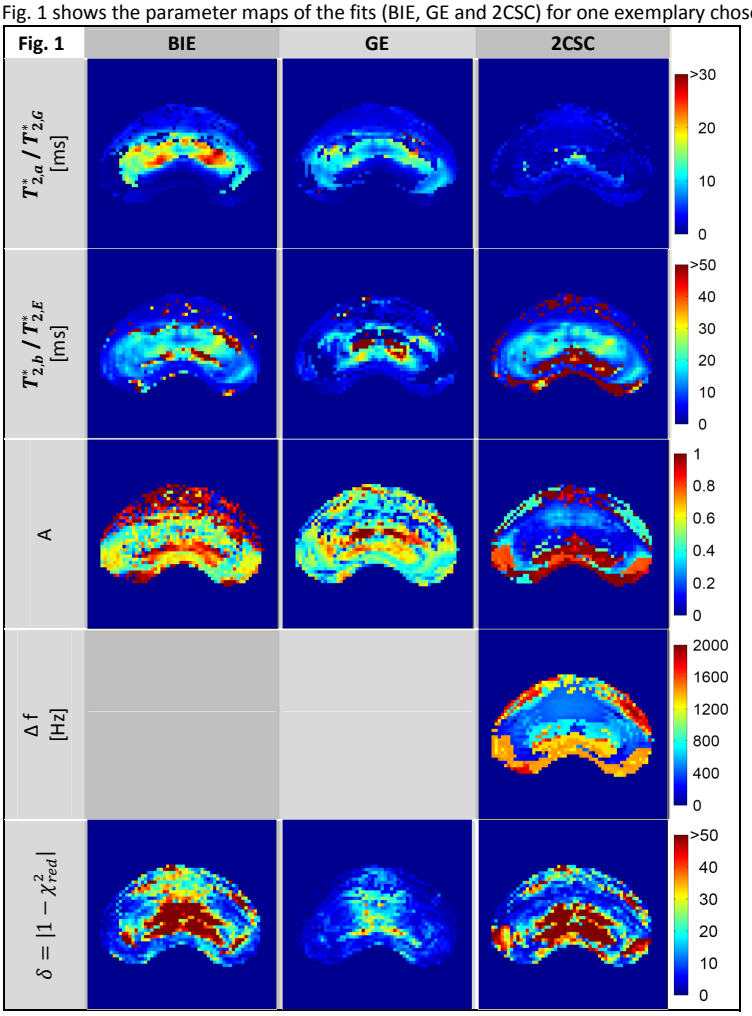
a) BIE: $S(TE) = S_0 \left[A\, exp(-TE/T^*_{2,a}) + (1-A)\, exp(-TE/T^*_{2,b}) \right]$, b) GE: $S(TE) = S_0 \left[A\, exp(-0.3606\,(TE/T^*_{2,G})^2) + (1-A)\, exp(-TE/T^*_{2,E}) \right]$,

where $1/(\pi\, T^*_{2,G})$ is the FWHM of the corresponding Gaussian lineshape in the frequency domain,

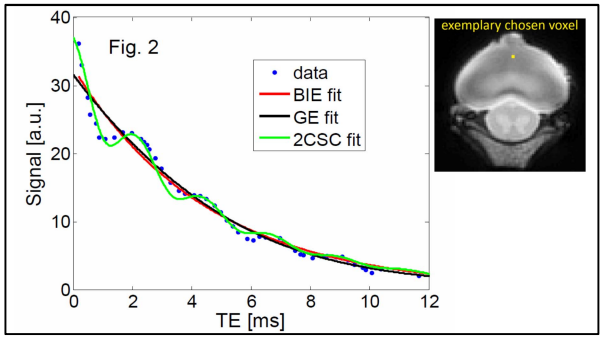
c) 2CSC: $S(TE) = S_0 \left[A^2\, exp(-2\,TE/T^*_{2,a}) + A\,(1-A)\, exp(-TE/T^*_{2,a})\; exp(-TE/T^*_{2,b})\, cos(2\pi\,\Delta f\; t_d) + (1-A)^2\, exp(-2\,TE/T^*_{2,b}) \right]^{1/2}$, where Δf is the frequency offset of the two chemically shifted components. To visualize the performance of the fit, the value $\delta = |1-\chi^2_{red}|$ was calculated pixel-wise for all fits.

Results and Discussion

Fig. 1 shows the parameter maps of the fits (BIE, GE and 2CSC) for one exemplary chosen porcine IVD.



In the outer collageneous ring of the IVD (*anulus fibrosus*), the BIE and the 2CSC fit yield relaxation times of < 1 ms up to 10 ms for the faster relaxing component, while $T_{2,G}$* obtained from the GE fit is in the same range. In the region of the gelatinous core of the IVD (*nucleus pulposus*) all three fits show comparable values for the slower relaxing component ($T_{2,b}$*), however high values of δ are obtained for the BIE and 2CSC fit. For comparison, the GE fit yields better performance in this region, yet the goodness of the fit is still not satisfactory. Interestingly, for each of the three fit functions, regions in the IVD can be found where the values of δ are lowest. This means that the signal decay is affected regionally by different physical effects (chemical shift, mesoscopic and macroscopic field inhomogeneities). Furthermore, this result suggests that it might not be possible to find a global analytical model that is applicable to the whole IVD. In Fig. 2 an exemplary signal decay observed in one voxel shows how strongly the T_2* relaxation curve can differ from an exponential decay (here caused by chemical shift modulation). These results demonstrate the complexity of modeling T_2* decays in the IVD. Therefore, interpretation of T_2* maps should be handled with great care. Alternatively, mapping of ultrashort T_2 could be used to investigate IVDs [4]. The applied 180° refocusing pulse will prevent signal decay alteration as seen in T_2* measurements. However, lower SNR/time compared to ultrashort T_2* mapping leads to longer measuring times which might present a problem during application *in vivo*.



References: [1] Mosher et al. Seminars in Musculoskeletal Radiology 08 (4) pp.355-368 (2004); [2] S. Kirsch et al. Proc. Intl. Soc. Mag. Reson. Med. 20, p.275 (2012); [3] Williams et al. Osteoarthritis and Cartilage 18 (4) pp.539-546 (2010); [4] S. Kirsch et al. J. Magn. Reson., 210 (1), pp.133-136 (2011).