

Accuracy and precision of Cartilage T2-relaxation time Quantification: Impact of the Fit method

J. G. Raya¹, O. Dietrich¹, A. Horng¹, J. Weber¹, J. Dinges¹, M. F. Reiser¹, and C. Glaser¹

¹Department of Clinical Radiology-Großhadern, Ludwig Maximilian University of Munich, Munich, Germany

Introduction: T2 relaxation time quantification has high potential for the diagnostic work up of cartilage, especially in early osteoarthritis. T2 calculation relies on fitting data acquired at different echo times (TE) from multi-echo sequences (MES) to an exponential equation, which is assumed to reflect transverse magnetization decay. The low T2 times in articular cartilage (between 10 and 50 ms) and the high resolution necessary to resolve the cartilage layers unavoidably result in low-SNR data for T2 calculation. Noise in MRI has a non-vanishing mean, so that (noise) signal intensities do not decrease at long TEs [1]. Therefore, fitting to an exponential function results in systematic overestimation of T2. Our objective was to assess the influence of the fitting procedure on the accuracy and precision of T2 relaxation times in articular cartilage.

Methods: Four different fit methods have been considered: a linear regression of the logarithmized signal intensities (LR); a non linear fit (Levenberg-Marquardt) to an exponential function (EXP); a voxel-based extension of the method proposed by Miller et al. [2], in which the squared signal intensities minus two times the variation of noise are fitted to an exponential function (SQEXP); and a newly introduced fit to a noise corrected exponential function (NCEXP). Accuracy (deviation of the calculated T2 values from the exact T2 values) and precision (spread of the calculated T2 values) were estimated for each method. Synthetic MRI images ($n=1200$, range of T2 from 10 to 110 ms and SNR at TE=0 between 15 and 120), and phantom MES image data acquired on nine test tubes (T2 range from 15 to 60 ms, SNR between 16 and 320) were used for accuracy and precision assessment. In simulations exact T2 were a priori known, whereas in phantom measurements the exact T2 times were assumed to be the T2 calculated in the highest SNR image. The accuracy was assessed by testing the coincidence of the mean of calculated T2 and the exact T2 (Wilcoxon test). Measured precision was compared with the theoretically predicted highest precision given by the Crámer-Rao lower bound (CRLB) (Levene test).

The impact of the different fits on in-vivo voxel-wise reproducibility of patellar cartilage T2 was measured in 6 healthy volunteers (7 consecutive measurements) with all four method. All 21 possible pairs of datasets of the same volunteer underwent rigid registration. After registration differences in T2 were calculated. Since no exact T2 is known in vivo, accuracy and precision were assessed in vivo by comparing the T2 values of the LR, EXP and SQEXP methods with the NCEXP method.

Results: Results of the simulations are presented in Fig. 1. The T2 values calculated with the NCEXP and SQEXP methods were both in simulations and phantom measurements compatible ($P<0.001$) with the exact T2 values for all SNR levels. On the contrary the LR and EXP methods lead to significant loss of accuracy. For T2=10 ms and SNR=15 the averaged deviation from exact T2 was 5.2% (SQEXP, $P=0.007$), 3.8% (NCEXP, $P=0.03$) 420% (EXP, $P<0.001$) and 790% (LR, $P<0.001$). The NCEXP presented the most precise T2 values, which for T2>20 ms and SNR>20 were compatible with the CRLB. The lowest precision was obtained with the SQEXP method, seen on the deviations of points from the CRLB.

Accuracy and precision of in vivo datasets are presented in Fig. 2. Since the NCEXP method demonstrated the highest accuracy and precision, NCEXP T2 values were used for comparative assessment of the accuracy and precision with the other three methods. As in simulations LR and EXP methods lead to high loss of accuracy (Fig. 2 top) and poor precision at low T2 values (Fig. 2 bottom). In vivo voxel-based precision was better with the NCEXP and SQEXP methods (mean SD of 9.0 and 9.0 ms) than the EXP (10.2 ms) and LR (15.3 ms) methods.

Conclusions: Noise correction significantly improves accuracy and in vivo precision of patellar cartilage T2 calculation. This technique may contribute to improve sensitivity in studies on OA based on cartilage T2.

References: [1] Gudbjartsson H et al. Magn Reson Med. 1995;34:910-4. [2] Miller AJ et al. Magn Reson Imaging. 1993;11:1051-6.

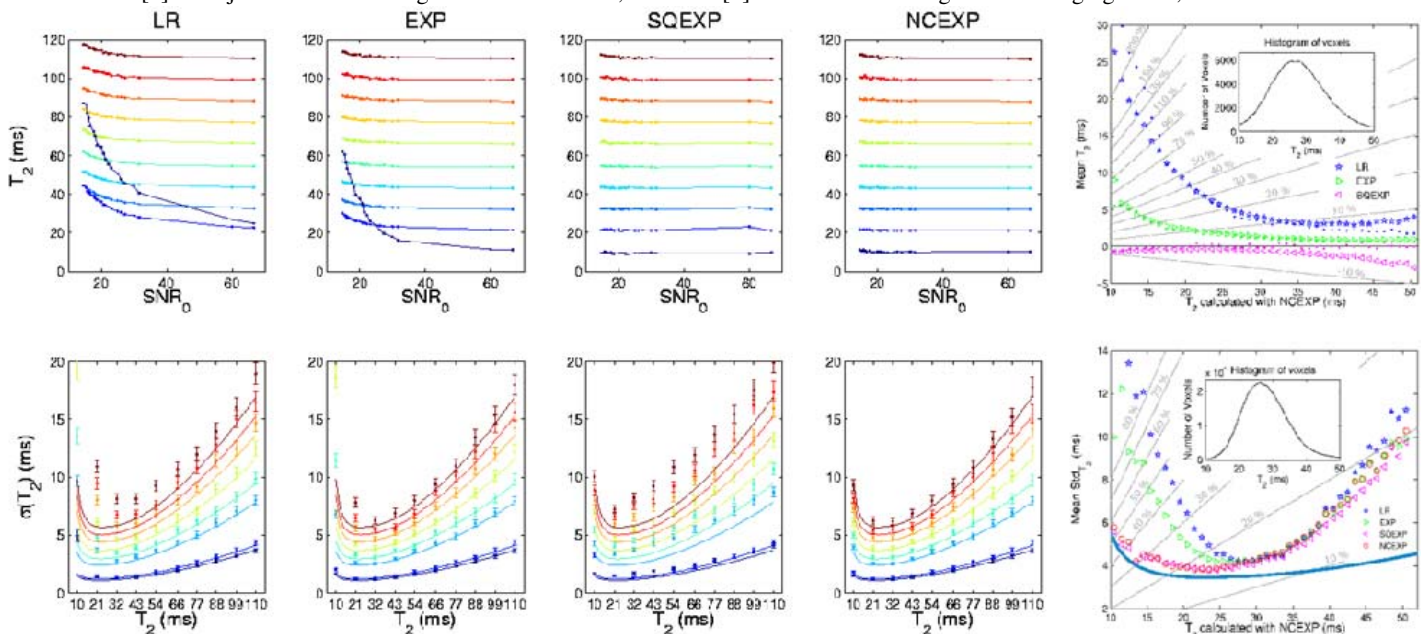


Figure 1: First row, the mean T2 plotted against the SNR. Colors encode different original T2 values. Second row, the standard deviation (SD) is plotted against the true T2 (points). Colors encode here different SNR levels. Error bars are the 99% confidence interval of the SD. Solid lines are the CRLB for the different SNR levels.

Figure 2: Accuracy (top) and precision (bottom) of the LR, EXP and SQEXP methods compared to the NCEXP method.