Maximum Likelihood Estimation of T1rho Relaxation Time in Lumbar Intervertebral Disc at 3T

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Target Audience: MRI physicist, radiologist, radiographer, medical imaging researcher.

Purpose: Noninvasive quantitative assessments for intervertebral disc degeneration become more important with the development of novel emerging treatment technologies for disc degeneration. T1rho relaxation, probes the interaction between water molecules and their macromolecular environment, and has been suggested to have potentials for identification of early disc degeneration [1-2]. Almost all T1rho mapping is performed by least-squares (LS) fitting that assumes the noise with Gaussian probability density function (PDF). However, magnitude MR images show Rician noise [3], which deviates considerably from Gaussian PDF at low SNRs and leads to the biased estimation of T1rho. This study proposes the use of maximum likelihood (ML) estimation [4] to reduce estimation bias and improve estimation accuracy for lumbar disc T1rho mapping, particularly at low signal-to-noise ratios (SNRs).

Methods: Monte-Carlo simulation ($n=10^4$) was performed to test ML T1rho estimation and compared to LS estimation for simulated exponential decay data imposed with Rician noise at spin-lock times (TSLs) of 1, 20, 40, 60, 80ms. True T1rho values were set as typical T1rho for annulus fibrosus (AF) of 50ms and nucleus pulposus (NP) of 100ms. Reference SNR was defined as the SNR at TSL=1ms. Lumbar disc T1rho scan was performed on 5 subjects using a fat-suppressed 3D bFFE sequence implemented with a rotary-echo spin-lock pulse on a 3T Philips Achieva MRI scanner with a spine coil [2]. Informed consents were obtained. Imaging parameters included: spin-lock frequency (FSL)=500Hz, TSLs=1, 10, 20, 40 and 60ms. (TSL=80ms was limited by RF amplifier restriction). TE/TR/TD (delay time)=2.4/4.6/6000ms, FOV/thickness=200/4mm. Voxel size= 1x1mm and FA=40^o. Images were voxel-wise fitted to a mono-exponential model S(TSL) =Aexp(T1rho/TSL) using ML and LS algorithm. Noise variance was estimated for ML from regions of background (SNR=0) that assumed to be Rayleigh distributed.

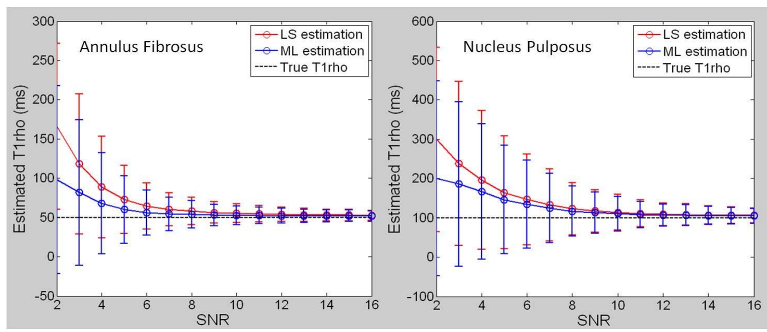

Fig.1. Simulation results of T1rho estimation (mean± std) by using ML and LS. True T1rho values were set as typical T1rho for AF (50ms) and NP (100ms). TSL=1, 20, 40, 60, 80ms.

Results: Monte-Carlo simulation results were shown in Fig. 1. For typical T1rho values for both AF and NP, ML obtained more accurate T1rho estimation than LS, particularly at SNRs<10. At higher SNRs, T1rho estimation by ML and LS was similar because Rician distribution approaches Gaussian distribution. For AF with low T1rho values, ML estimation approached true t1rho more rapidly with SNR. Simulation results were verified by lumbar spine T1rho mapping (Fig. 2). Endplates, AFs and NPs were better delineated in the ML generated T1rho map than in LS generated one. The T1rho histograms within the disc L4/5 (Fig. 4) by ML and LS were plotted in Fig. 3. The estimated T1rho values were much smaller by using ML than LS in AF (T1rho<50ms) but quite similar in NP with higher T1rho values.

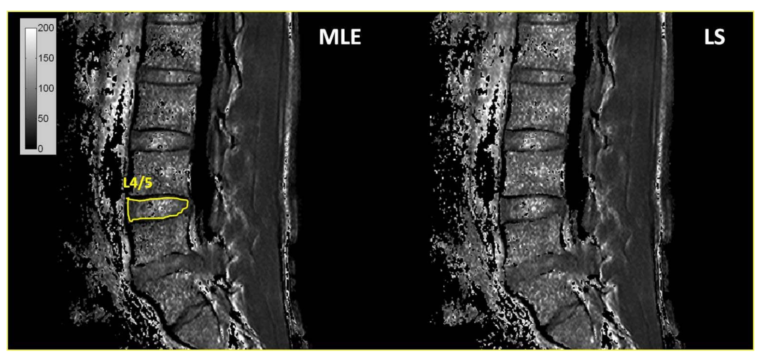

Fig.2. Comparison of lumbar spine T1rho maps generated by ML and LS estimation.

Discussion: ML is an unbiased estimator of which the variance attains the lowest possible value, i.e. the Cramer-Rao lower bound. According to the simulation, ML obtained lower mean T1rho estimation and closer to true T1rho values than LS, particularly at the SNRs below 10, while the estimation STDs of ML were comparable with LS. ML is able to increase spatial resolution of lumbar disc T1rho imaging without sacrificing the accuracy of T1rho mapping and hence benefits disc degeneration evaluation. ML also has limitations. It requires the estimation of noise variance that influences the ML estimation accuracy. The calculation of maximum PDF for ML is much more computationally intensive than LS.

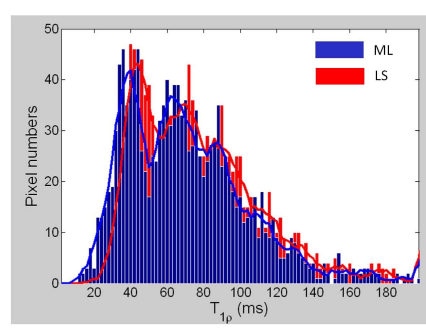

Fig.3. Histograms of T1rho in disc L4/5 by using ML and LS

Conclusion: ML provides less biased and more accurate estimation of lumbar disc T1rho compared to LS, particularly at low SNRs. It benefits high spatial resolution spine T1rho imaging without compromising the accuracy of T1rho estimation. This work is supported by HK RGC grant CUHK418811 and SEG_CUHK02. **References:** [1] Blumenkrantz G, et al, MRM 2010, 63:1193-1200; [2] Wang YX et al, Eur Radiol, 2012, in press; [3] Gudbjartsson H, et al, MRM 1995, 34:910-4; [4] Silbers J, et al, IEEE-TMI 1998, 17:357-61.