

Cross-Regularised Relaxographic Imaging

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Introduction: The inverse Laplace transform of multi-echo or inverse recovery time series is an ill-conditioned problem requiring a regularisation that constrains the continuous distribution $s(T_1)$ or $s(T_2)$ – coined relaxogram¹ – based on a prior knowledge. When no specific prior knowledge is available, the general-purpose regulariser applies the principle of parsimony by imposing a smooth solution, thus privileging solutions with broad, unskewed and mesokurtic peaks. The relevant information of *auto-regularised* continuous distributions are the number of peaks, their respective intensities and positions. In systems made of a mixture of broad and sharp peaks, such *auto-regularisation* will perform poorly, resulting in a loss of resolution. To take advantage of the spatial information provided by relaxographic imaging, we introduce a novel regularisation method based on the partial volume effect. It imposes a cross-regularisation between neighbouring pixels. Peaks of the resulting pixel relaxograms may display any shape or pattern as long as such feature is shared with neighbouring pixels. The corresponding *dia-regulariser* was constructed with a Laplace image filter (Fig. 1) and implemented with Contin². It was compared with the performance of the built-in general-purpose Contin *auto-regulariser*. As the computational complexity grows approximately with the cube of the size of the problem, we were limited to 5 by 5 pixels sub-images and a maximum of 40 grid points.

Methods: *Phantom study:* spherical phantom holding a solution of 0.25 mM MnCl₂ and 75 mM NaCl, 32 TI values geometrically increased from 11 ms up to 5 T₁, one 128x128 slice acquired at 4 T (Varian/Siemens) with the PURR-TURBO sequence (data kindly provided by J.-H. Lee, see Ref. 3). *In vivo study:* 12 mm cylindric probes of a juvenile pig (ca. 9 months old) femoral and tibial pair of knee lateral condyles, kindly prepared by S. Löster (Univ. Leipzig, Germany), stored in a 0.9% NaCl and 0.5 mM ethyl mercury thiosalicylate solution at 5°C, multi-echoes studies measured within four days at 18°C in a fresh 0.9% NaCl solution; 50 multi-echoes, TE=7 ms, TR=7 sec, 256x256 matrix, 7.1 T micro-imaging Bruker AMX (Erlangen, Germany), pixel size 0.1x0.1x1 mm³, 2 accumulations with quadrature cycling; a slice was chosen to display tibial radial and femoral tangential zones, acquired at 6 angles with respect to B₀ static field (0°, 18°, 34°, 44°, 64° and 90°), then the femoral bone was submitted to increasing hydraulic pressures (0, 50, 100, 150, 200 and 300 kPa, see Ref. 4 for apparatus details).

Results: In Fig. 1 a dramatic increase in the T₁ resolution of the doped phantom is observed with the Laplace *dia-regulariser* in comparison with the general-purpose Contin *auto-regulariser* (Norder=2). In Fig. 2 the position of the main T₂ relaxogram peak of the tibial radial cartilage zone follows the expected increase when nearing the magic angle (54.7°) which can be observed both in *auto-* and *cross-regularised* relaxograms (Ng=30 grid points). The Laplace *dia-regulariser* was able to resolve additional features on both sides of the main peak. The pixel displayed in Fig. 2 is near the interface of the radial with the isotropic zone of the cartilage surface. The extra features computed by the *dia-regulariser* may be due to a combination of fibre orientations within that pixel: shorter T₂ for those oriented towards B₀ and larger T₂ for those oriented towards the magic angle. Fig. 3 exemplifies the effect of a low hydraulic pressure of 50 kPa in the femoral tangential zones in which no signal intensity changes are expected according to the literature.⁴ The *dia-regulariser* was capable of detecting a modification in the relaxogram shape at 50 kPa, suggesting that changes occur in tangential cartilage zones although not detectable by MRI contrast methods.

Conclusion: The *cross-regularisation* is applying a conservative prior-knowledge (smoothness) in dimensions of relaxographic imaging orthogonal to that of the relaxogram, thus avoiding unnecessary broadening of relaxation peaks. Our investigation showed a drastic increase in the relaxogram resolution which should provide a better chance of detecting small changes in relaxation distributions at the pixel level such as in the case of early tumour detection. Although the physical importance of the pattern of the relaxogram remains challenged, our results with cartilage offers perspectives for the non-invasive observation of rheumatoid conditions.

References: [1] Labadie C. et al. (1994) *J. Magn. Reson. B* **105**:99-112. [2] Provencher S.W. (1982) *Computer. Phys. Comm.* **27**:229-242. [3] Lee J.-H. (2000) *Magn. Reson. Med.* **43**:773-777. [4] Gründer W. et al. (2000) *Magn. Reson. Med.* **43**:884-891.

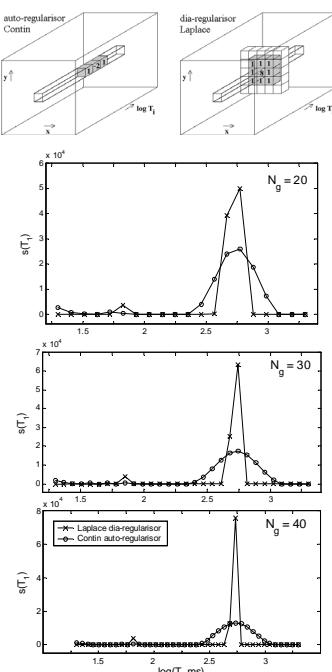


Fig. 1

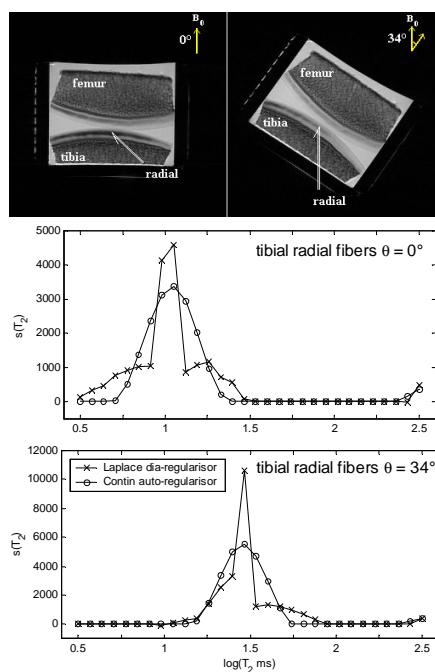


Fig. 2

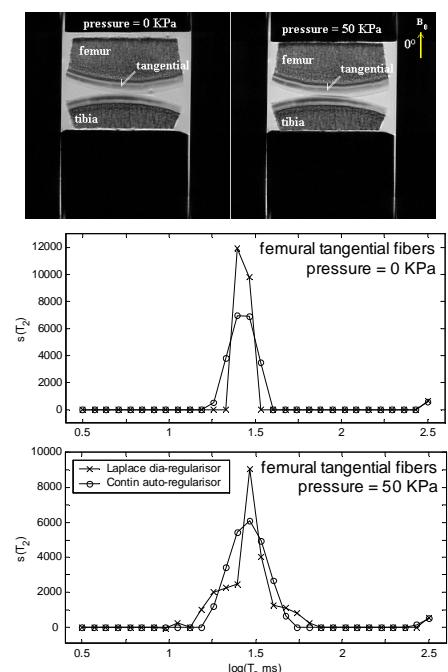


Fig. 3