T_2 Linear Combination Filtering in Patella Cartilage

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Introduction: T_2 varies substantially with location in cartilage. Possible explanations may be related to cartilage orientation and regional differences [1,2]. Multi-exponential decay in the knee cartilage has been described in the literature [2]. To analyze this effect least squares (LS) based multi-exponential curve fitting is traditionally employed. However this is method requires a very high signal to noise ratio (SNR) [3], making it difficult to conduct multi-exponential curve fits on a pixel by pixel basis *in-vivo*. T_2 linear combination (LC) filters are a promising alternative to multi-exponential T_2 curve fit based analysis to study various T_2 components [4]. In this work we apply three T_2 LC filters (short T_2 5-15 ms, medium 30-50 ms and long >100 ms) to an eight echo dataset obtained by scanning the patella of normal volunteers.

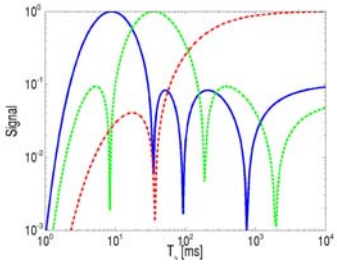

Figure 1: Signal versus T2 for the three filters. The first is designed to pass short T2 species (5-15 ms), while the other two are designed for medium (30-50 ms) and long (100 ms and above) T2 species.

Theory: Using the signal equation a linear combination of different echo times is expressed in Eq. 1. This equation is used to quantify the signal contribution of a given T_2 species where l is proportional to that T_2 species abundance.

$$\text{FilteredImage}(T_2) = \Sigma_i \, l \, e^{TE_i/T_2} \quad (1)$$

The T_2 axis is divided into either a pass, stop or a don't care band. If a T_2 falls in the passband, then Eq. 1 should yield a large number, while if the T_2 falls in the stopband Eq. 1 should give a small value. Noise gain of a linear combination is given by the norm of the weights. The problem is to select a set of weights such that the average passband SNR is maximized, subject to the stopband having no more than a given percentage of the average passband signal. This can be formulated as a second order cone program, and solved using computationally efficient methods [5]. For this work the YALMIP and SeDuMi Matlab © packages were used [6]. Three T_2 LC filters are designed. The first with a T_2 passband of 5-15 ms aimed at short T_2 species such as those found in tendons. The second with a passband from 30 to 50 ms designed to pass cartilage and the third filter passes T_2 species from 100 ms and up for synovial fluid [2,7].

Methods: Using a GE Signa 1.5 T LX scanner with a 3-inch surface coil placed externally on the patella two healthy volunteers were scanned. Eight serial spin echo scans were acquired using TE = 9/14/22/34/53/82/128/200 ms. T_1 weighting is kept constant by using TR = 1309/1314/1322/1334/1353/1382/1428/1500 ms [4]. The images were filtered using the three T_2 filters described above. SNR simulations were performed to verify the ability of the three T_2 filter approach to discriminate between T_2 species from each of the passbands. A T_2 was chosen at random from one of the passbands, and a signal having that T2 was simulated. Then each of the three filters were applied. This was done 2048 times for each of the filters for SNR of 10 and 100 (SNR being determined as the signal over the standard deviation of the noise at TE=9 ms), measurements were made of how often the filter with the correct passband gave the highest LC filter score.

Results: Figure 1 shows the short, medium and long T_2 filtered images from a healthy volunteer along with a spin echo anatomic image (TR/TE = 1382/82 ms) of the same slice. From the SNR simulations we found that for an SNR of 10, more than 95% of the time the filter with the correct passband had the highest filter score of the three filters. With an SNR of 100 more than 99.5% of the time the filter with the correct passband has the highest score.

Discussion: The filtered images show interesting contrast in the patella of femoral cartilage. From the literature T_2 in femoral cartilage varies with position. This has been associated with structural variations in the cartilage causing T_2 shortening at the center [1,2]. On the short T_2 image, a slight band in the center of the cartilage can be seen. Fenrich et al, found that a minimum SNR of 500 was required to fully separate T_2 peaks located a factor 5 apart using a LS based multi-exponential fit method [3]. At SNR values in the diagnostic range (10-100) our SNR simulations indicate that the three LC filters achieve good separation of T_2 species, even though they are only a factor 4 apart on the average. LC T_2 filtering is a promising alternative to LS based curve fit approaches. Currently we are working on optimizing the echo times, which could reduce the number of echoes needed for the LC method [4].

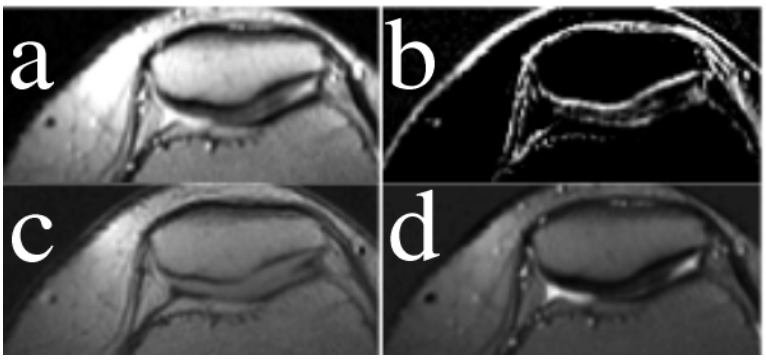

Figure 2: (a) An anatomic image of the femoral cartilage of a healthy volunteer (TR/TE 1382/82 ms). (b) A short T2 (5-15 ms) filtered image of the same region, (c) a medium T2 (30-50 ms) and (d) a long T2 (100 and above) filtered images.

References:

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