Performance of two-sequence, two-inversion pulse PERFIDI filters to suppress and/or quantify relaxation time components in multicomponent systems

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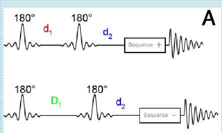
Objectives: *P*arametrically *E*nabled *R*elaxation *F*ilters with *D*ouble and multiple *I*nversion (**PERFIDI**) represent a method useful in NMR/MRI to quantify and/or suppress components of NMR signals. They resemble the electronic *band-pass, high-pass* or *low-pass* filters, but are used to separate sample components according to their longitudinal relaxation times during data acquisition and prior to data evaluation. Their effect is not to exactly zero the signal at a discrete number of T_1 values (like STIR, DIR and MIR), but to attenuate it strongly in a selected range of T_1 values, while the remaining signal is affected only in a moderate, computable way. Based on this method, a protocol for a very fast determination of the ratio between ^{1}H of fat and total signal without using the time consuming Inversion–Recovery data acquisition has been developed and applied to biological samples. The PERFIDI method has been also applied to MRI in order to obtain well T_1 contrasted images.

The PERFIDI sequence



PERFIDI: the simplest PERFIDI filters are obtained subtracting the signals of 2 sequences, each with a preamble of 2 RF inversion pulses, as shown on the left. Depending on the choice of the delays one can obtain *low-pass, high-pass* or *band-pass* filters, according to the following equation:

$$F(r; D_1, d_1, d_2) = \eta(1+\eta)(e^{-rd_1} - e^{-rD_1})e^{-rd_2}$$

where F indicates the attenuated signal, normalized to the equilibrium magnetization, r is the longitudinal relaxation rate and n is the inversion efficiency of π rf pulse.

The required condition for *low-pass* (useful in order to suppress fat) is $D_1 \rightarrow \infty$, that in terms of NMR measurements means $D_1 \approx$ Recycle Delay, for *high-pass* $d_1 \rightarrow 0$, all the other combination lead up to *band-pass.* Different values of the delays move the filter to different positions and change its attenuation profile.

The PERFIDI preambles can work with every sequence: They have been already tested with Single Pulse (in order to acquire FID), Inversion Recovery, CPMG and Spin-Echo.

Materials & Methods

Hardware: All images were obtained by *Artoscan* MRI apparatus (*Esaote*, Genova, Italy). Relaxometry data were acquired with a home-built relaxometer composed of the *Artoscan* permanent magnet (0.2 T) and a *Spinmaster* console (*Stelar*, Mede, PV, Italy).

Software: The ILT data inversion was performed by UpenWin. A dedicated C++ software was developed to predict the effect of any PERFIDI filter over a known distribution of T_1's and find the best values of the delays to be used in real experiments.

Samples: In biological tissues, fat and lean can be distinguished because of different longitudinal relaxation times, respectively in the range 30-200ms and 200-500ms.

Phantoms:
Phantoms were prepared to mimic the T_1 distribution of muscles in order to obtain samples with different ratios of the short component signal to the total signal. The goal was to obtain samples behaving like mixtures of fat and lean, but in which the ratio between the components are well known. To achieve this goal, we have used several tubes with different concentrations of EDTA in water. The ratios chosen for the samples, expressed as the percentage of the signals arising from lower peak over the total signal [F/(F+W)] are: 60, 40, 30, 27, 18, 15, 12, 10, 7.7(from C1 to C9, respectively).

FAST–PERFIDI: This is a new method which permits an extremely fast evaluation of the ratio between the signal arising from fat and the total signal of the sample (fat + water), without using IR. The FAST-PERFIDI method consists of the following steps:

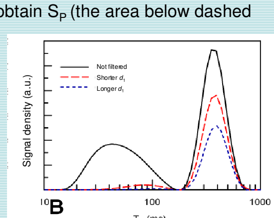
1 - acquisition of the FID with a zero-PERFIDI (that means a sequence with ineffective PERFIDI preamble, delays equal to zero). The extrapolation to $t_{FID} = 0$ gives S_{ZP};

2 - acquisition of the FID with a two-pulse two-sequence PERFIDI filter to get a PERFIDI low pass filter. The extrapolation to $t_{FID} = 0$ permits to obtain S_P (the area below dashed line in Fig. **B**).

3 - computation of the non attenuated signal assigned to "water" $S_W = S_P/TA$ (the area below the right peak, solid line, Fig. **B**). TA is the total attenuation of the "water" peak i.e. the computed mean attenuation introduced over the range of water's T_1

4 - computation of the signal from fat: $S_F = S_{ZP} - S_W$ (the area below the left peak, solid line);

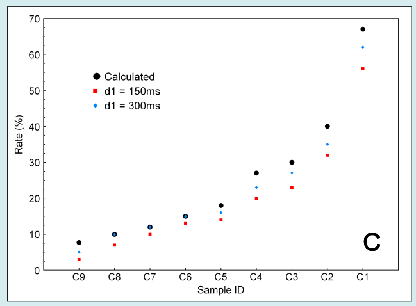
5 - computation of the ratio $F/(F+W) = S_F/S_{ZP}$, to be compared with the experimentally known F/(F+W).



Results

a) Applications to Relaxometry

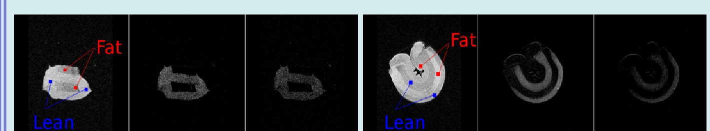
The choice of delays which characterize the low-pass filter has been made in order to suppress the shorter T_1 peak in Fig. **B**. The result of a simulation of PERFIDI filter is reported as dashed line. In the same figure one can appreciate the attenuation of the other peak. The "Not filtered curve" refers to sample C9, and is obtained by IR data.



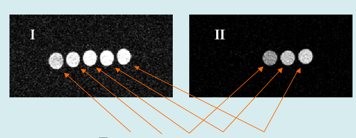
In Fig. **C**, the outcomes of the evaluation of the ratio *F/(F+W)* obtained with two different delays are reported. Results are compared with the calculated rate of the lower peak against the overall signals F/(F+W). The best results have been achieved with the 300 ms filter, while the other shows a larger and systematic underestimation.

b) Applications to MRI

PERFIDI can be used also in MRI to suppress the signal from fat in samples containing both lean and fat. This leads to better contrasted and more significant images.
Below are reported two sets of MRI images of two different samples: for each series the first image is a Spin Echo, while the second and the third ones are obtained using the PERFIDI method, with respective delays [d_1=300 ms, d_2=5ms] and [d_1=450 ms, d_2=5ms]. It is evident that the PERFIDI filter with te delay d_1=300 ms suppress very well just the signals of fat, while if the delay is longer, the signals from lean are also attenuated.



Below: A quantitative validation of PERFIDI applied to MRI has been carried out using tubes filled with solutions having different concentrations of EDTA in water. The first image reported below (**I**) is a Spin Echo with Echo Time equal to 18 ms and Repetition Time of 2000 ms. It is useful as reference for the position of samples: 5 tubes with increasing T_1 from left to right. The second image (**II**) is obtained by low-pass filter PERFIDI with d_1 = 300 ms. The goal is reached: the first and the second tube (with T_1 in the range of fat) disappear in the filtered image. The signal attenuation in the last three circles is in good and agrees with simulations: the mismatch is less than 10%.



T_1 = 30, 70, 270, 350, 470 ms

Conclusions: A new method for a fast determination of the ratio of the ^{1}H fat signal to the total signal in muscle tissues has been proposed. It is based on a comparison of the signal obtained with a low-pass PERFIDI filter and a simple FID signal. The method avoids the need to use time consuming magnetization recovery sequences such as IR. On phantoms prepared to mimic muscle tissue with increasing fat content, the method makes it possible to quantify the ratios "fat/(fat+water)" with relative errors smaller than 15% for values in the range 10-70%.
The PERFIDI method is also applicable to MRI with good results in order to obtain well contrasted images or to suppress signals over a wide zone of T_1 distribution; this statement has been demonstrated both on samples made with biological tissues and on test tubes filled with solutions of EDTA and water.

References:

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V. Bortolotti, P. Fantazzini, M. Gombia, D. Greco, G. Rinaldin, S. Sykora, *"PERFIDI filters to suppress and/or quantify relaxation time components in multicomponent systems: an example for fat-water systems"*, in press J. Magn. Reson. 206 (2010) 219-226. Doi: 10.1016/j.jmr.2010.07.010

Web-site link: www.ebyte.it/perfidi/Perfidi.html, This poster's DOI: 10.3247/sl3nmr10.004