# Processing of MR images weighted by relaxation time $T_2$ to increase their resolution

*[1] K. Bartusek, [2] Z. Smekal*

[1] Institute of Scientific Instruments, Academy of Sciences of the Czech Republic, Kralovopolska 147, 612 64 Brno, Czech Republic
Email: bar@isibrno.cz
[2] Department of Telecommunications, Faculty of Electrical Engineering and Communication, Brno University of Technology, Purkynova 118, 612 00, Czech Republic
Email: smekal@feec.vutbr.cz

***Abstract.*** *The paper deals with the possibility to increase resolution in a measured MR image weighted by relaxation constant $T_2$ of nuclei in the sample via suppressing spin density weighting. This method of image processing is based on measuring the MR of images by the spin echo technique for two time values ($T_E$) and on the calculation of their quotient.*

*Keywords: MR Images, Relaxation Times, Spin Density Suppression*

## 1. Introduction

Magnetic resonance is one of the most important and advanced medical diagnostic techniques. In images detected by the technique of magnetic resonance (MR images) it is possible to distinguish the properties of individual human tissues, the distribution of proton nuclei, and imaging the difference in the relaxation properties of nuclei in the tissues being measured. These parameters can be used to obtain a more accurate diagnosis of the disease.

The magnitude contrast in an MR image is given by many physical parameters of live tissues. The most important parameters are the amounts of proton nuclei, relaxation times $T_1$ and $T_2$, and the kinetics of molecules of water (such as flows, diffusion and perfusion) [1]. Contrast in an MR image always depends on several parameters simultaneously. By choosing the type of the measuring pulse sequence and by setting its parameters such as the spin echo time $T_E$, the time of repeating the experiment $T_R$, the magnitude of slip angle, the time of nucleus inversion $T_I$, etc., the contrast given by one of the above parameters can be increased and, simultaneously, the effect of the other parameters reduced. In this way it is possible to increase the contrast and make visible the pathological areas of the tissue examined [2]. [3].

The amount of proton nuclei - the spin density - determines the basic contrast of MR images, and changing it can be used to affect the contrast. The present paper describes a measuring method suitable to distinguish between the effect of weighting the MR image by spin density and by relaxation time $T_2$ of sample nuclei. This method of image processing is based on measuring the MR of images by the spin echo technique for two time values ($T_E$) and on the calculation of their quotient**.** The result is an MR image weighted by relaxation time $T_2$ with the effect of this spin density suppressed.

## 2. Proposed method of measuring and processing

One of the current techniques of detecting MR images is the spin echo (SE) method [4]. The obtained image of a chosen layer is weighted by spin density $M_0(x, y)$ and, simultaneously, by the magnitude of relaxation constant $T_2$. The effects of spin-lattice

relaxation and diffusion can be considered negligible. The magnitude of an MR image can be expressed by the expression:

$$M(x,y) = M_0(x,y)\,\mathrm{e}^{-\frac{T_\mathrm{E}}{T_2}} \tag{1}$$

In the commonly conducted experiments for the determination of relaxation times $T_2$ it is necessary to measure a series of images with different echo times $T_\mathrm{E}$. To obtain an image weighted by value $T_2$ it is necessary to perform approximation in its individual places. In this way the effect of spin density in the chosen place can be limited. A simplified method consists in measuring one MR image for a suitably chosen value $T_\mathrm{E}$. In this case the image magnitude will not be weighted by relaxation times several times shorter than the chosen time $T_\mathrm{E}$, and the contrast in the image will correspond to relaxation times $T_2 > T_\mathrm{E}$. For a more accurate determination of the spin relaxation time in a chosen local place of the image it is of advantage to eliminate the effect of spin density. We measure the MR images for two times $T_\mathrm{E}$. On the basis of definition (1) their magnitudes can be expressed as follows:

$$M_1(x,y) = M_0(x,y)\,\mathrm{e}^{-\frac{T_{\mathrm{E}1}}{T_2}} \tag{2}$$

$$M_2(x,y) = M_0(x,y)\,\mathrm{e}^{-\frac{T_{\mathrm{E}2}}{T_2}} \tag{3}$$

Time $T_{\mathrm{E}1}$ should be as short as possible and it is limited by the measuring sequence and by the magnitudes of the gradients used. Time $T_{\mathrm{E}2}$ is chosen according to the assumed relaxation times in the sample measured (50 - 200 ms). The quotient of images $M_1(x, y)$ and $M_2(x, y)$ can be used to eliminate the effect of spin density on the contrast of MR image:

$$\frac{M_1(x,y)}{M_2(x,y)} = \mathrm{e}^{-\frac{T_{\mathrm{E}1}-T_{\mathrm{E}2}}{T_2}} \tag{4}$$

Taking the logarithm of relation (4) will change the quotient of images into their difference and the magnitude of resulting image will be weighted only by the relaxation time $T_2$ according to the relation:

$$M_T = \ln\frac{M_1(x,y)}{M_2(x,y)} = \ln M_1(x,y) - \ln M_2(x,y) = -\frac{T_{\mathrm{E}1}-T_{\mathrm{E}2}}{T_2} \tag{5}$$

At each point of the image the relaxation times are then given by the relation:

$$T_2 = -\frac{T_{\mathrm{E}1}-T_{\mathrm{E}2}}{\ln M_1(x,y) - \ln M_2(x,y)} \tag{6}$$

The processing of images in the above way is limited by the noise in the image because noise is enhanced by this modification.

## 3. Experimental verification of proposed method

Experimental verification was performed on a 200 MHz MR scanner in the Institute of Scientific Instruments of the Czech Academy of Sciences in Brno. To verify the methods of image processing, the images of phantoms with different relaxation times $T_2$ were measured for two times $T_\mathrm{E}$ = 11 ms and 100 ms. The phantom, Fig. 1, consisted of five cuvettes, with the cuvette designated 1 filled with a solution of water and cadmium, cuvette 2 filled with

distilled water and cuvettes 3, 4 and 5 filled with a solution of water and nickel sulphate of different concentrations. The cuvette axes werfe oriented in the direction of axis *z*.

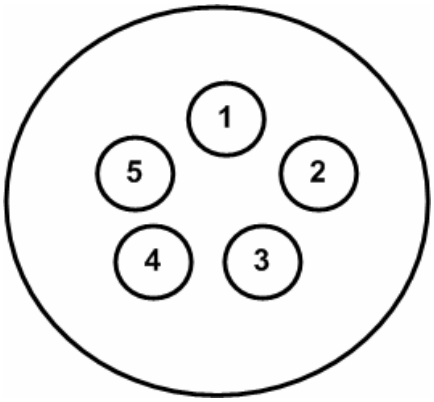


Fig. 1. Illustration of the testing phantom.

First, the method of spin echo without the application of magnetic field gradients was used to measure the relaxation times $T_2$ , separately for each cuvette. These values, given in Table 1, are reference values. The values measured have not been affected by the diffusion of nuclei in samples.

Table 1. Values measured on the phantom

| Sample No | Composition | $T_2$ |
|---|---|---|
| 1 | water + Cd | 401 |
| 2 | deionized water | 381 |
| 3 | water + nickel sulphate - 0.5 | 211 |
| 4 | water + nickel sulphate - 1 | 128 |
| 5 | water + nickel sulphate - 2 | 103 |

Using the MR method of spin echo, images were measured in the *x, y* plane for two times $T_E$ = 11 ms and 100 ms. Fig. 2 gives the two images measured. Taking their logarithms and subtracting them we obtain an image with $T_2$ contrast with the spin density contrast eliminated, Fig. 3. Table 2 gives the relaxation times $T_2$ determined from modified images and compared with reference values.

The method described can also be used with advantage to measure biological samples. Figs 4 and 5 give a comparison of images weighted by spin density and relaxation times and the same images after eliminating the spin density contrast for a 2 mm section through an egg and a lemon, detected by the SE method on an MR scanner of the Institute of Scientific Instruments of the Czech Academy of Sciences in Brno. The centre of the yolk has a different density but the relaxation time is the same in the whole yolk, $T_2$ = 27 ms. The relaxation time of the white of egg is $T_2$ = 125 ms.

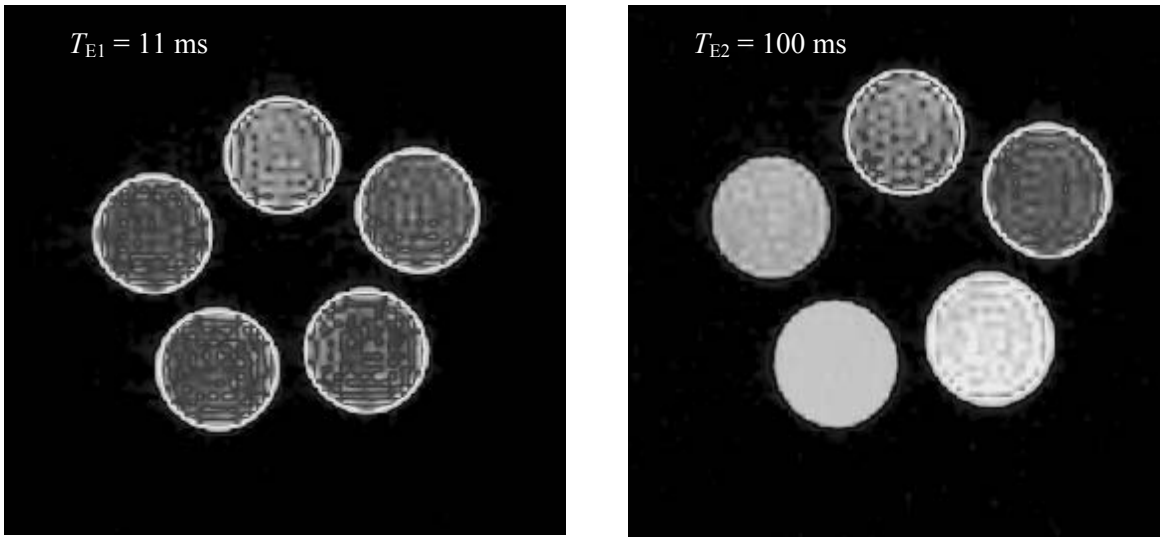


Fig. 2. Testing MR images of phantom, measured for times $T_E$ = 11 ms and $T_E$ = 100 ms (60x60 mm, 256 pixels, MR method SE).

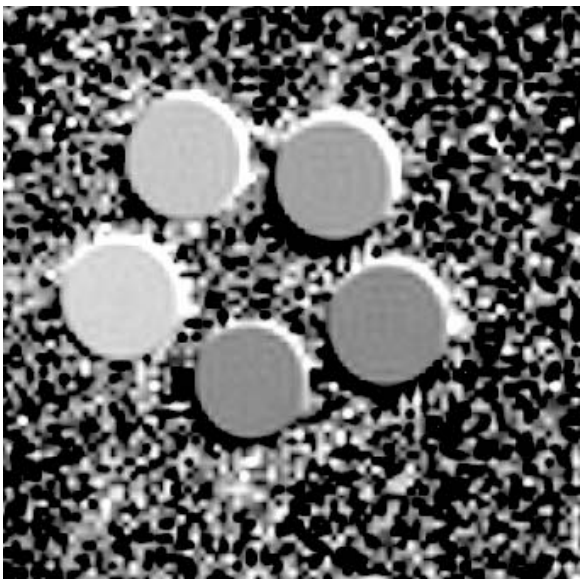

Fig. 3. Image of phantom after processing by the method described.

Table 2. Comparison of reference values with measured relaxation times for individual samples.

| Sample No | 1 | 2 | 3 | 4 | 5 | note |
|---|---|---|---|---|---|---|
| $T_2$ | 401 | 381 | 211 | 128 | 103 | measured by SE method, without gradient,without diffusion |
| $M_T$ | 0,14 | 0,125 | 0,320 | 0,707 | 0,884 3 | subtracted from modified image for $T_E$ = 10 and 100 ms |
| $T_2$ | 636 | 712 | 278 | 125 | 100,6 | |

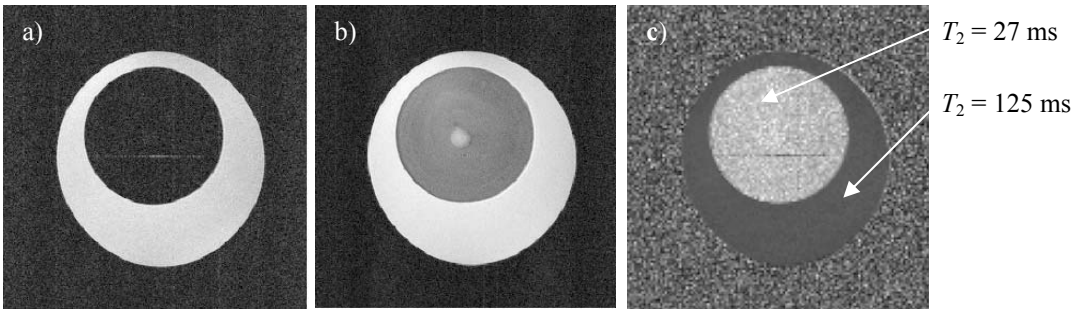


Fig. 4. Image of egg weighted by spin density and relaxation time $T_2$, measured a) for $T_E$ = 100 ms, b) for $T_E$ = 10 ms, and c) image weighted by $T_2$ after elimination of spin density.

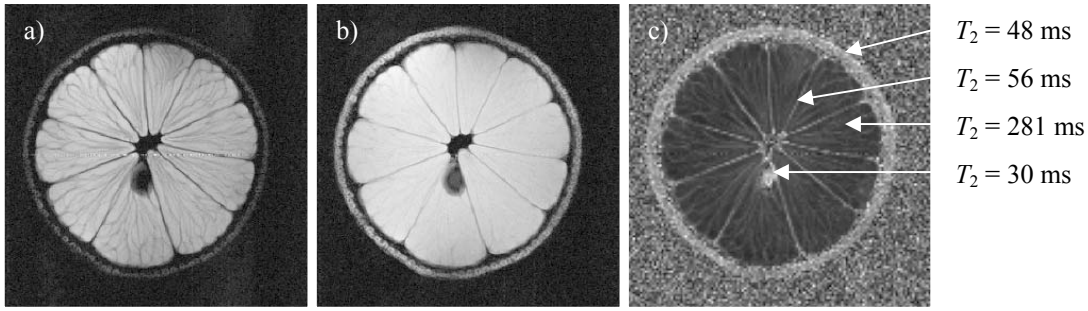


Fig. 5. Image of lemon weighted by spin density and relaxation time $T_2$, measured for a) $T_E$ = 100 ms, b) for $T_E$ = 10 ms, and c) image weighted by $T_2$ after elimination of spin density.

For the lemon, four areas with different relaxation times can be distinguished. For the rind, membrane or pip the relaxation times are short (30 - 56 ms) and the juice relaxes very slowly (281 ms).

## 4. Conclusions

The above method of modifying MR imaging enables the weighting by relaxation time $T_2$ in the image detected to be enhanced and the spin density contrast to be suppressed. This modification of the image will provide for a more accurate evaluation of areas with different relaxations, which is of particular advantage in medicine when determining the patient's diagnosis. It is obvious that this method cannot be used to resolve a mixture of substances with different relaxation times occurring in one spot of the object examined. Likewise, areas without an MR signal cannot be evaluated either.

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