MRI visualization of pathological forms by suppression of normal tissue signals

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ABSTRACT

To improve the visualization and 3D-reconstruction of some pathological formations of the brain, it is offered to use a new method of processing of MR images with suppression of signals from normal tissues. The special attention is offered to be given suppression of signals of fatty tissue, free water and partially bound water of mucous membranes. For such way realization, it is offered to lead two scans with simultaneous suppression of two normal components and to multiply the obtained images. Simultaneous suppression of signals from two normal tissues is realized with the help of pulse sequence twice using inversion-recovery effect. Delays in pulse sequence are selected in accordance with the times of longitudinal relaxation of fat, free water and partially bound water. In comparison with earlier described technique of simultaneous suppression of signals of water and fat, the new method is especially useful at research of pathological formations when the zone of defeat is placed in a zone of nose bosoms. Besides allocation of a zone of defeat, MIP reconstruction becomes simpler. The offered technique well proves at research of tumors and hemorrhages.

Keywords: image contrast enhancement, normal tissue signal suppression, inversion-recovery, MR-image multiplication, 3D-construction, MIP-processing

1. INTRODUCTION

Typical medical MRI investigation in the case of indefinite clinic diagnosis consists usually from two stages. On the first stage, an analysis of normal structures is fulfilled and, if there are suspicions on pathological tissues, the second stage is carried out when the best visualization is realized for pathologies likely tumors, hemorrhage zones, cysts, etc.

During brain pathology investigations, it's advisable to get MRI images where normal tissues are presented by homogeneous background or completely suppressed. First of all, it relates to the tissues which give too strong signal by MRI scanning that decreases sensitivity of receiver and create excessive bright image on the background of which it's difficult to reveal changes of contrast related with pathology. It especially concerns the T2-weighted images (T2-WI). These tissues are unbound water and fat. Unbound water is contained in ventricles, grooves, eyeballs. Fat is in subcutaneous tissue, orbits, cranial-vertebral transition field.

Now in MRI practice, the methods realizing a spin suppression of any tissue component are used widely [1]. Methods on the base of inversion-recovery effect are applied most frequently. These methods realize relaxation time selection of tissues. For fat signal suppression, STIR (Short Time Inversion Recovery) method is used, and for water suppression - FLAIR (Fluid Attenuated Inversion Recovery) one.

MRI experience showed that suppression of only one component is not enough in some cases for reliable pathology revelation. It is especially sufficient when a pathology zone borders upon both region containing sufficient quantity of water and fat tissue. Therefore in some cases, combined suppression water and fat signals is used. Usually for this goal, the SPIR method is applied (SPIR uses mechanism of chemical shift suppression (CSS) of fat signals) in combination with FLAIR regime. Based on a chemical shift suppression of signals from unwished for visualization tissue methods use frequency-selective excitation of spins. Therefore they are very sensitive to magnetic field inhomogeneity. CSS-methods are restricted ordinarily by investigations of small zone of scanning – for example, for orbit investigation [2-4].

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However in some cases, CSS-methods are more preferable than based on tissue selection by relaxation time ones. For instance, during investigations with paramagnetic contrast matter injection, longitudinal relaxation time is shortened for a tissue in which the contrast matter is accumulated. As a result it becomes difficult to execute tissue selection by relaxation times.

Application of methods based on the inversion-recovery procedure is prospective for simultaneous suppression of water and fat signals. Such methods are insensitive to frequency adjusting and magnetic fields inhomogeneity. Experiments, where simultaneous suppression of water and fat signals were provided by double inversion of magnetization, were described before. Suppression effect was reached by that reading began in just that moment when longitudinal magnetizations of both water and fat passed through zero magnitude as a result of relaxation transition from inverse state to equilibrium one [5-8].

Double inversion mechanism is applied not only for water and fat signal suppression. It is used as well for suppression of other tissues with different times of longitudinal relaxation. For example, it is made by investigations of vascular walls with contrast matter injection as far as in the case it is necessary in equal power to suppress both usual blood and the blood transferring contrast matter [9].

Due to simultaneous suppression of strong signals of water and fat, dynamic range of receiver is spread, a tissue contrast picture becomes simpler, especially in comparison of conditions of pathological formation visualization become better, and volumetric processing is improved.

2. PURPOSE

In the paper we will show some opportunities for control by tissue contrast which are created during MRI investigation by using double inversion mechanism. In comparison with earlier described material, we will spare special attention to experiments in which suppression of water signals is led till not zero but till definite level where a contained water tissue contrast coincides with white or grey matter. Besides of that we will demonstrate how it is possible to get MR images where signals are suppressed not only from two but from three and possibly more number of normal tissue components. We will appreciate as well opportunities of pathological formation visualization and demonstrate possibilities of their volume processing.

3. METHODS

3.1 Pulse sequence

For realization of simultaneous water and fat suppression, MRI scanning was applied the pulse sequence "180^0-TI_W-180^0-TI_F-(90^0-acquisition)". The parameters TI_W, TI_F corresponded approximately to TI values given in FLAIR and STIR regimes. For indicated regimes, the values were equal TI=T1ln2=0.69T1, where T1 is the longitudinal time of suppressing tissue. Curves describing behavior of longitudinal magnetization and signal dependence on relaxation time are presented on the Fig. 1, 2.

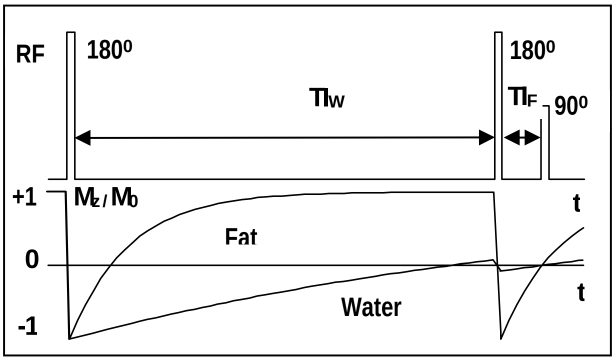

Figure1: Diagram of pulse sequence (upper curve) and evolution of longitudinal magnetization of fat and water (lower curves) for the sequence 180^0-TI_W-180^0-TI_F

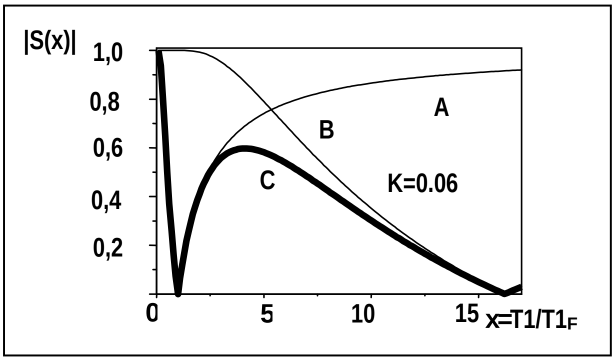

Figure2: Signal dependence on T1 for methods based on the "inversion-recovery" effect – A - STIR, B – FLAIR, C – the sequence 180^0-TI_W-180^0-TI_F .

It is easy to see the conditions of simultaneous transition through zero for magnetizations with different relaxation velocities are created with help of the second inverting pulse by change of initial magnitudes of their longitudinal magnetizations.

Calculation of the curve Fig. 2 is given in [10]. It carried out for the vector Bloch model in assumption that duration of pulses is small in comparison with relaxation time T2 and the value 1/?, where ? - chemical shift range, and filling frequency of RF-pulse is close to Larmor frequency of investigated spins. Under the conditions, one cannot consider transversal components of magnetization vector, and the parameters T2 and ? do not include to the final result. In the end for the $T1_F/T1_W << 1$, we have

$$S_c(x) = |1-2(1-\exp(-(\ln 2/x)(1/k+1))\exp(-\ln 2/x)|,$$

where $k=T1_F/T1_W$, and $x=T1/T1_F$.

One can observe the curve C is close to the graph obtained by multiplication of plots A and B, calculated for regimes STIR and FLAIR accordingly. The plots A and B are described accordingly by formulae:

$$S_A(x)= |1-2*\exp(-(\ln 2)/x)| \text{ and } S_B(z)= |1-2*\exp(-(\ln 2)/kx)|.$$

The range of T1 magnitudes, where the curve C decays no more than in 2 times, in enough wide – it occupies the interval about 0.2-1.1 seconds for the magnetic field 0.5 Tesla. Just in the range, there are T1 values belonging to a series of pathological changes – sites of demyelinization, zones of edema, hemorrhages, cavernoma, some tumors, etc. (Fig. 3). Therefore after simultaneous water and fat signal suppression, these pathological formations look as the most definitely on the background of suppressed signals from normal structures, in particular from cerebrospinal fluid and hypodermic fat.

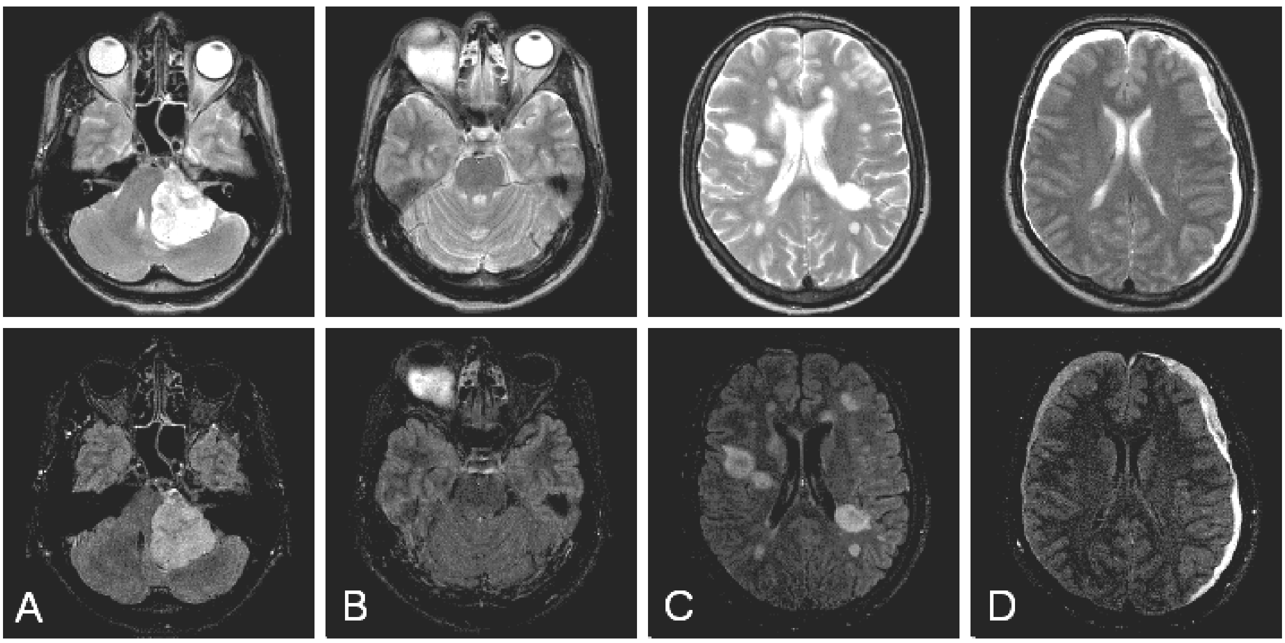

Figure 3: Visualization of pathological changes at T2-WI (upper line) and by simultaneous suppression of water and fat signals (lower one): A – neurinoma, B – hemorrhage in orbit, C – multiple sclerosis, D – bilateral sub-dural hematoma. Examples are given for different patients.

It is necessary to note that value of useful signal for regime with simultaneous suppression of water and fat signals is lower in 1.5 times in comparison with STIR and FLAIR regimes. Therefore for supporting suitable signal/noise ratio, it was necessary to enlarge number of accumulation from 2 till 3 with correspondent enlargement of scanning time. It is. It is possible, that this problem will not be actual at use of high field MR-scanner, where signal/noise ratio is high enough.

3.2 Delays adjustment for suppression of given tissue

TI_F was given equal to 80 ms for fat signal suppression. Hypodermic fat is suppressed well in the STIR regime by such value of TI parameter. In the same time, acceptable results are obtained by fat suppression in orbits and cranio-vertebral transition.

Full suppression of water signals is realized by value TI_W = 1300 ms. In experiments with partial suppression of water signals, delay TI_W was chosen by special way. For example, if it needed to level differences in contrast between water and white matter, that TI_W was given 1050 ms. In experiments where it was needed to level differences in contrast between water and grey matter, the value TI_W was given to 1800 ms. These values are matched good with theoretical one which was got analyzing exponential law of magnetization recovery for given values of relaxation times T1's and experimentally measured relations between initial magnitudes of longitudinal magnetizations.

Besides of simultaneous suppression of water and fat signals, experiments with simultaneous suppression of fat and mucous sinus signals were carried out. Such experiments are realized in the full analogy with experiment on full suppression of water and fat signals but it was adapted to shorter relaxation times of fluid, therefore TI_W was given here 600 ms.

To create MR images on which signals of three normal tissues (water, fat, and mucous) are suppressed, two scans were fulfilled – first with simultaneous water and fat signal suppression, after that – fat and mucous one. Obtained two MR images were multiplied between themselves and new MR image was got. The signal intensity for each point of the new image was proportional to multiplication of intensities of correspondent points of multiplied images. Special software was developed for this multiplication operation.

3.3 Typical scanning parameters

All described experiments were made on the 0.5 Tesla MRI-scanner TOMIKON S50 (BRUKER). By settlement of experiments with water and fat suppression for the pulse sequence, parameters were given by such way to orientate onto suppression of needed tissue components with saving T2-WI (T2 weighed image) of MR images.

Therefore usually delays were given as TI_W = 1300 or 1800 ms for water, 500 ms for mucous, TI_F = 80 ms for fat, TE_{av} = 0.1 s, TR = 5.5 s. As the 180^0 pulses, slice-selected Hermit ones with 3.6 ms duration from 2 kW transmitter were used with application of program-controlled attenuator with 1-4 dB damping.

Reading was realized by the method Fast Spin-Echo (or RARE [11]) – with 8-12 fold using of 180^0 refocusing pulses to stimulate spin-echoes in combination with multi-slice scanning algorithm - till 22 axial slices about 17x20 cm^2 cross-section and 4-6-mm thickness. Digital resolution at the scanning plane made up 1x1 mm^2 with using 256x256 maximum size of matrix. Scanning time for each circle of registration with 3 averagings (NEX = 3) was 5-6 min. Image processing was carried out in by ParaVision(TM) v.1.0 program. This program was modified to transform FLAIR regime into pulse sequence with double inversion recovery mechanism.

Let us note that transition from the FLAIR (STIR) regime, where one inverting pulse is applied, to the regime with simultaneous suppression of water and fat signals, where two inverting 180^0-pulses is used, does not create significant improvement of RF loading for the patient. In the practice, 10 RF pulses take part in the FLAIR-RARE regime – one 180^0 inverting pulse, one 90^0 one for reading a signal and 8 refocusing 180^0 pulses. In twice inverting pulse sequence, there are 11 pulses instead of 10 ones, and RF loading increases only on 10%.

4. RESULTS

Advantages of simultaneous suppression of normal tissue signals are revealed most definitely in the case when pathological zone is placed near by these tissue displacement zones. As regards water and fat, the simultaneous suppression of these tissue signals is very useful when closed to meninges zones.

4.1 Revealing the changes in meninges

An example demonstrating revealing of changes in meninges after surgery on sub-dural hematoma removal is shown on the Fig. 4. These changes (increasing of signal on T2-WI) are covered by fissure and hypodermic fat signals. Separate suppression of these signals (see fragments B and C) does not give a wanted result. In both cases, there are several peaks on graph of signal intensity changes along the horizontal axis passing through defeat zone. Only for the simultaneous suppression of water and fat signals, changed signal is revealed distinctly and even gives the scale of brightness on the MR image. In

this case there is only single peak on the graph of signal intensity (fragment D). It is that signal which was required to be revealed.
Due to suppression of strong signals from normal tissues, dynamic range of receiver is expanded. Its amplification (receiver gain) is optimized automatically on the relation to the level of pathological formation signal. It allows revealing contrast variations inaccessible to usual methods.

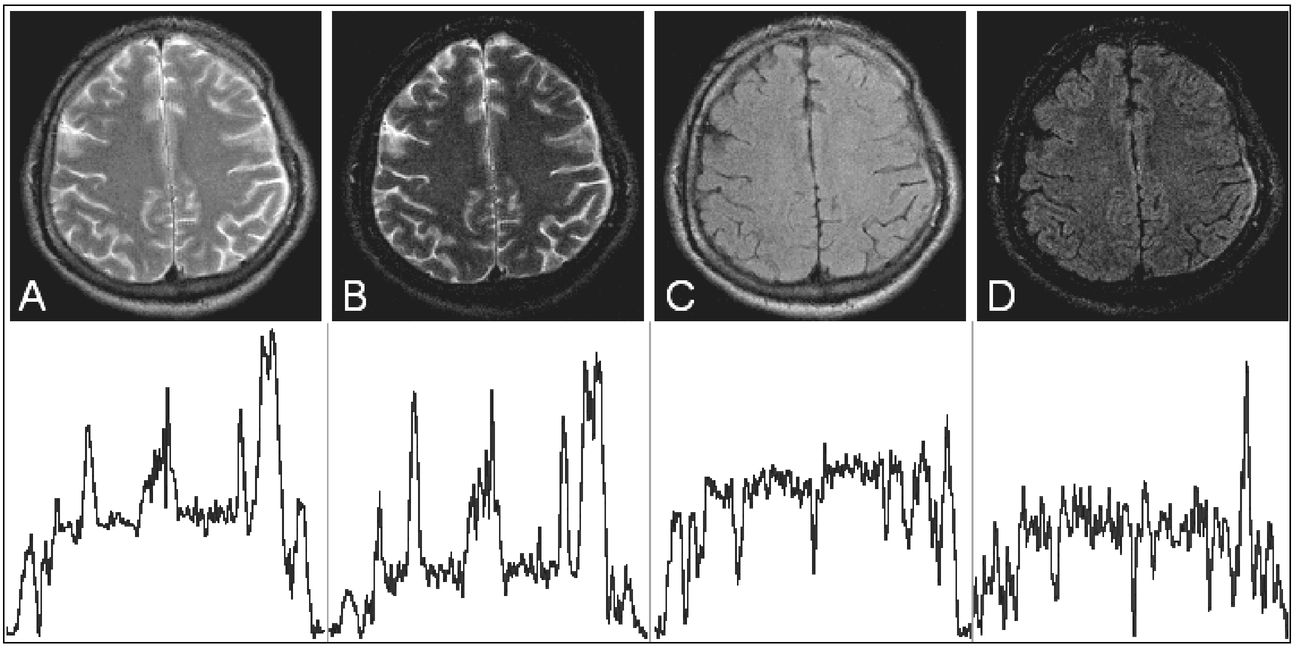

Figure 4: Visualization of changes in the meninges connected with sub-dural hematoma removal surgery (K., m., 38 y.). A – T2-WI, B – STIR, C – FLAIR, D- regime with simultaneous suppression of water and fat signals. Below – graphs of signal intensity changes along the horizontal axis passing through defeat zone.

4.2 Revealing the artery-venous malformation

The other example – revealing of a small artery-venous malformation at the left temporal region (Fig. 5). The pathology is placed in a zone of meninges and quite invisible on the usual MR images obtained by routine survey. Strong signals from hypodermic fat and CSF mask signal from thick blood vessels. Only by simultaneous suppression of water and fat signals, bright vessel signals are revealed and MIP reconstruction allows presenting more obvious vessel pathology presence.

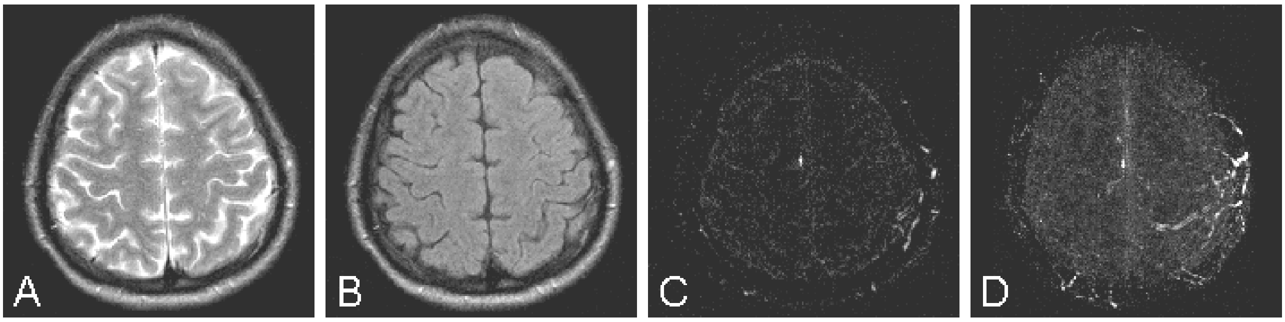

Figure 5: Revelation of artery-venous malformation of the patient B. (m., 32 y.) in the regime of simultaneous suppression of water and fat signals (C) with following MIP reconstruction (D). On the left MR images for the same scanning zone obtained in the regimes: A – T2-WI and B – FLAIR.

4.3 Visualization of changes in ventricle walls

Full suppression of water signal does not create always the most favorable conditions of pathology visualization. Sharp lowering of MR contrast on the border of transition between white brain matter and brain ventricle interferes to visualization of pathologies in zones joining to ventricle walls. Application of the FLAIR regime with water signal suppression till the level of grey matter allows better to reveal changes in ventricle walls (Fig. 6).

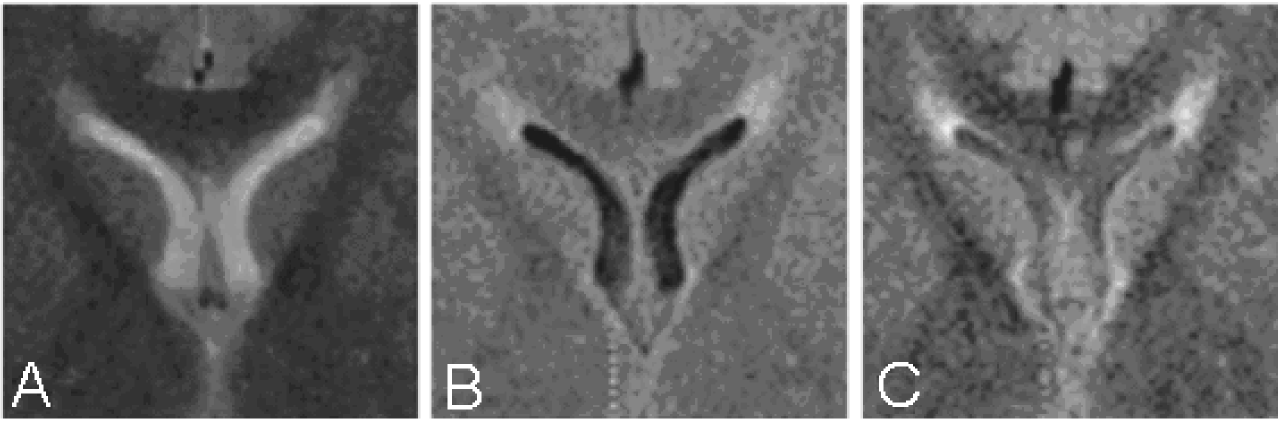

Figure 6: Visualization of brain ventricles in the conditions of edema by hydrocephaly. C – FLAIR (TI = 1300 ms), D – FLAIR (TI = 1800 ms). On the fragment D, changes in the ventricle walls are defined most distinctly.

Special opportunities appear by realization the FLAIR regime with suppression of water signal till white matter level (Fig. 7). The borders of ventricles and cysts are visible very distinctly on the tissue background.

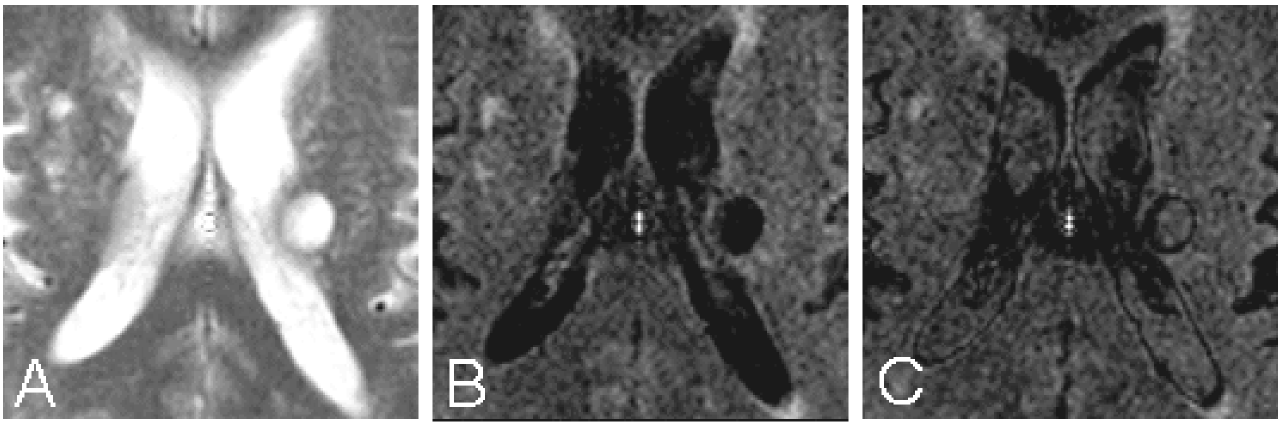

Figure 7: Visualization of liquor cyst for different parameters TI of the FLAIR regime. A – T2-WI, B – FLAIR (TI = 1.3 s), C – FLAIR (TI = 1.05 s).

4.4 Volume measurement of defeat zone

Simplification of tissue contrast picture by simultaneous suppression of water and fat signals creates favorable conditions for measurement of defeat zone volume. It is suitable to use MIP reconstruction (it would be better to have them in three orthogonal projections) for the rough urgent evaluation of relative volume changes. It is possible to apply simple algorithm to evident display of dynamics of a gain of a zone of defeat – Fig.8. First we make MIP-reconstruction from MRI data. Then we use the graphic editor to fill with paint bright area on each of two images. After we do logic multiplication of two colored images. Finally we obtain the image in which the bright zone reflects initial zone of defeat, and the grey frame reflects volume changes.

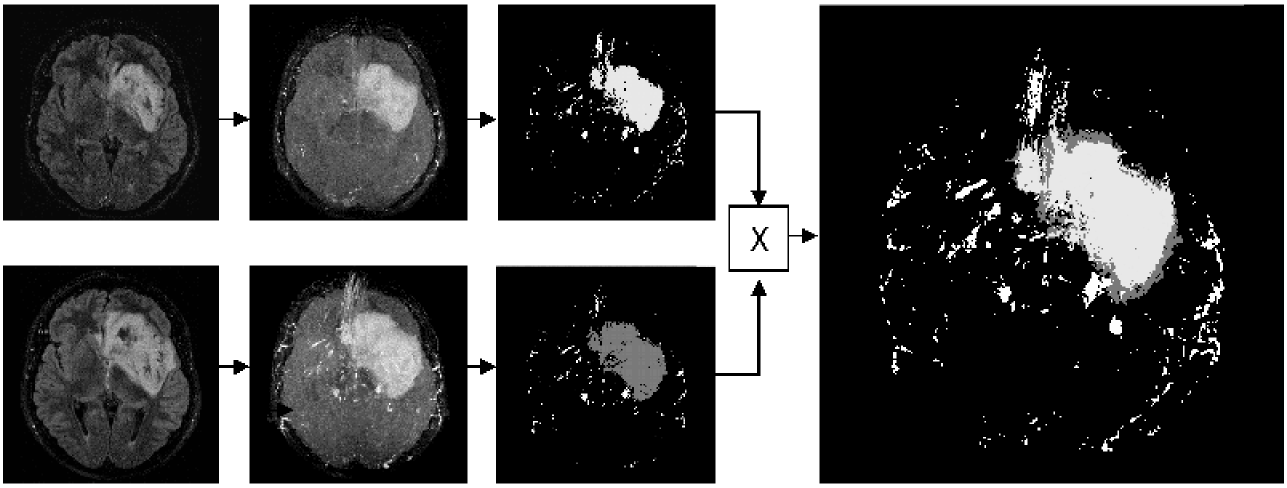

Figure 8: Visualization of tumor increase zone for two-year period with using MIP reconstruction.

For calculation of tumor volume, one can apply usual plane slices. Pathology segmentation is carried out on every slice and measured its area. For the calculation of volume, it is necessary to sum results of measurements on all slices. We developed correspondent program product for operation in MS Windows-XP medium (Fig. 9).

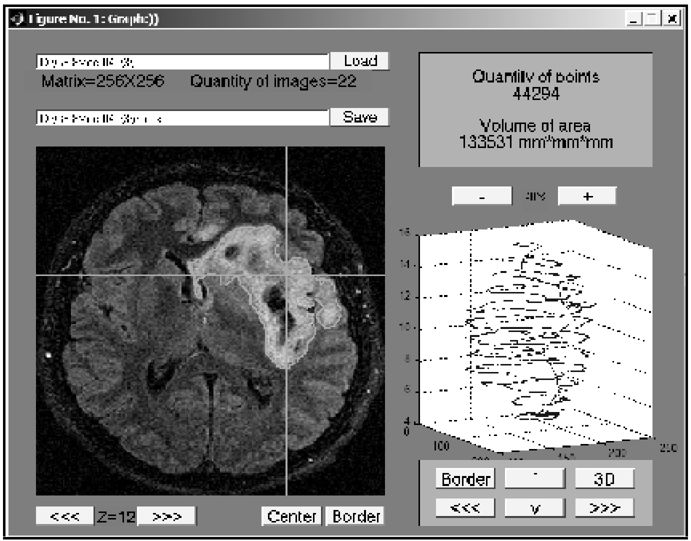

Figure 9: Interface of the program for calculation of defeat zone volume. Left – one from calculated slices. The cross indicates to internal point of segmented region. Right – 3D-presentation of segmented slices.

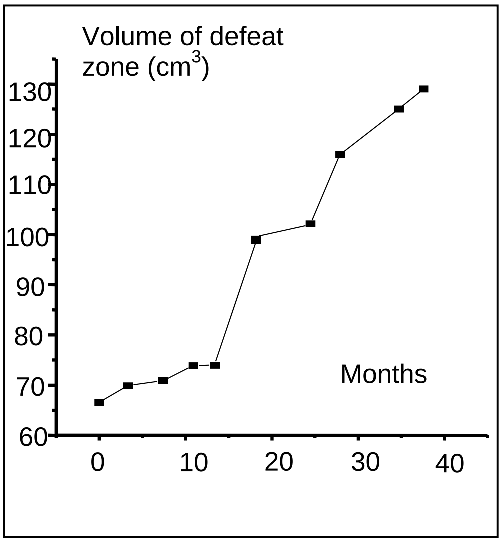

Figure 10: Dynamics of defeat zone volume changes for astrocytoma tumor (B., m., 34 y.).

We lead for about 3 years the investigations of patient with inoperable tumor (astrocytoma) in conditions when the patient refused from chemical therapy. For this time he was investigated more 10 times in the regime with simultaneous suppression of water and fat signals. For each investigation, the volume of defeat zone was measured and tumor evolution graph was constructed for 3-year period (Fig. 10).

4.5 Three-component suppression

One can observe that some considerable signal from sinus tissues is left after processing in the regime with simultaneous suppression of water and fat signals. It creates an extra “trash” during “clearing” of MR picture from normal tissue image. Therefore the problem “to clear” MR image from those components as well. A two-stage solution became optimal one. First stage – scanning with suppression of water and fat signals. Then – scanning with suppression of fat and mucous signals. In the last case, the same twice inverting pulse sequence as before was applied but with other time of inversion TI = 600 ms. After, multiplication of images (point-by-point multiplication of signal intensities) was made (Fig. 11). New image is actually an emulation of image from hypothetical regime MR scanning with simultaneous three normal tissue components suppression.

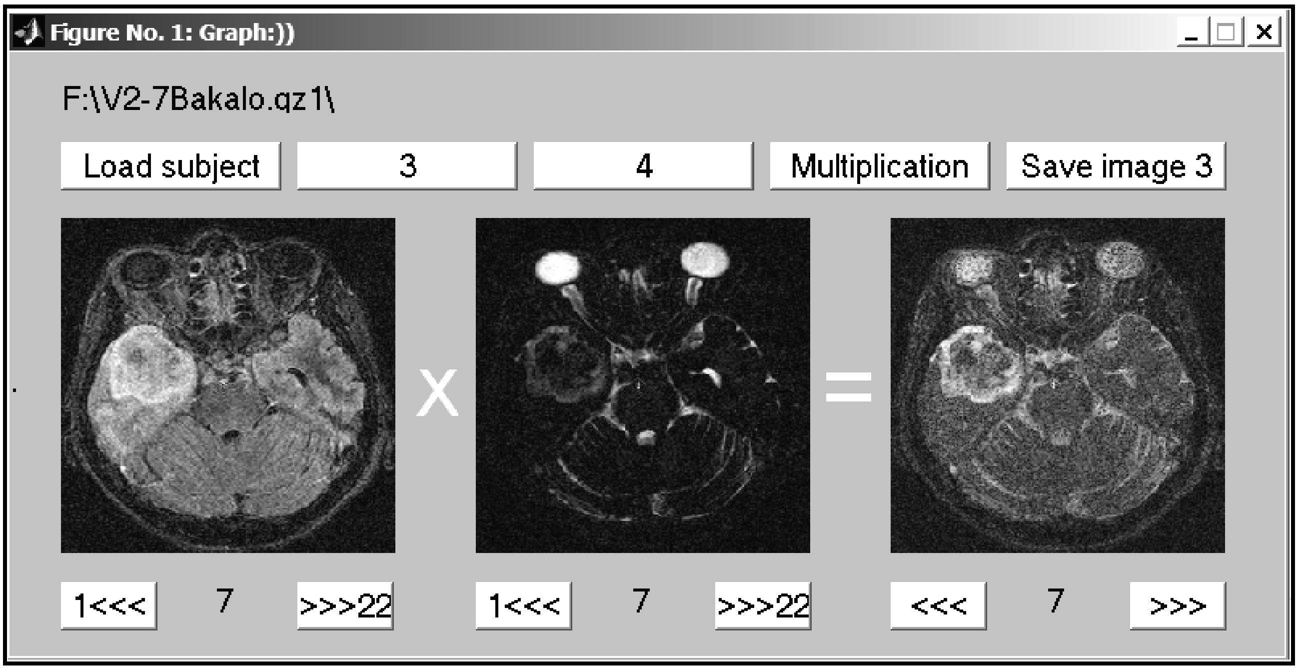

Figure 11: Interface of the program for image multiplication.

As a result, a new image contains only that was not suppressed on the both previous stages. Only that information, which is needed for tumor investigation, leaves on the plane slices and MIP-reconstructions. It was found possible because time of tumor longitudinal relaxation differs enough from three suppressed values – 110 ms, 860 ms and 1860 ms (Fig. 12).

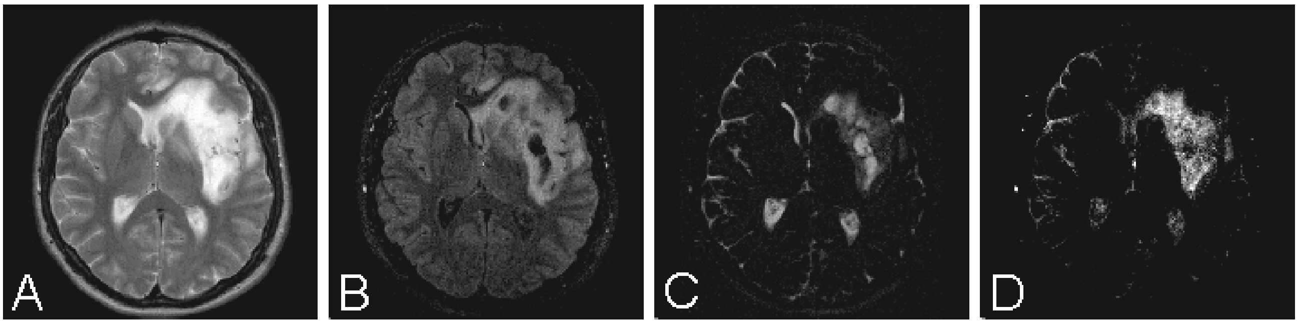

Figure 12: A – T2-WI, B – regime with simultaneous suppression of fat and mucous signals, C – regime with simultaneous suppression of water and fat signals, D – result of multiplication B and C.

It is possible to compare MIP reconstructions and 3D-rendering for two-component and three-component suppression (Fig. 13). It is easy to see that defeat zone volume for three-component suppression is some less than for two-component one. It is connected with that for suppression of mucous signals, the signals on borders of vasogeneous edema in the defeat zone are suppressed also as relaxation properties of this component is close to relaxation ones of the mucous.

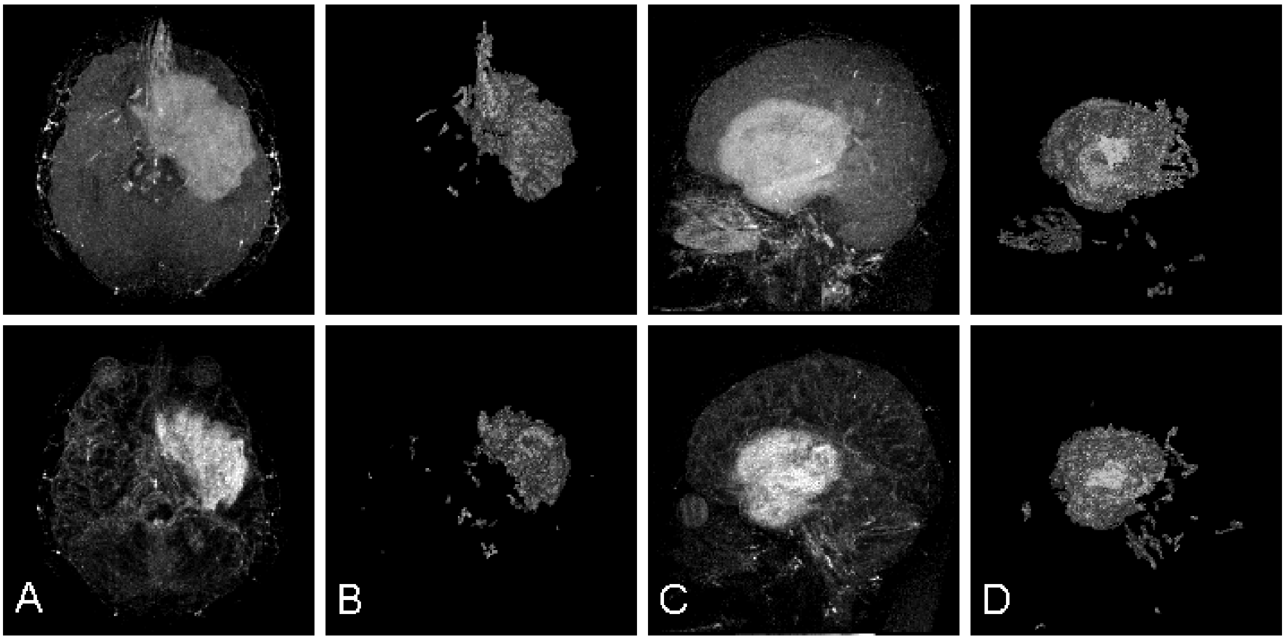

Figure 13: Upper row – volume reconstructions for the data obtained with simultaneous suppression of water and fat signals. A and B – MIP reconstructions and 3D-rendering for axial projection. C and D – MIP reconstructions and 3D-rendering for sagittal projection. Lower row – analogical volume reconstructions in the same foreshortenings that in upper row for the data from measurements with application of algorithm with three-component suppression of normal tissue signals.

Therefore MR images with mucous suppression, and practically with suppression of tissues owing longitudinal relaxation time 860 ms can be used for additional differentiation of pathological tissues in a defeat zone, for example, hemorrhage zone (Fig. 14).

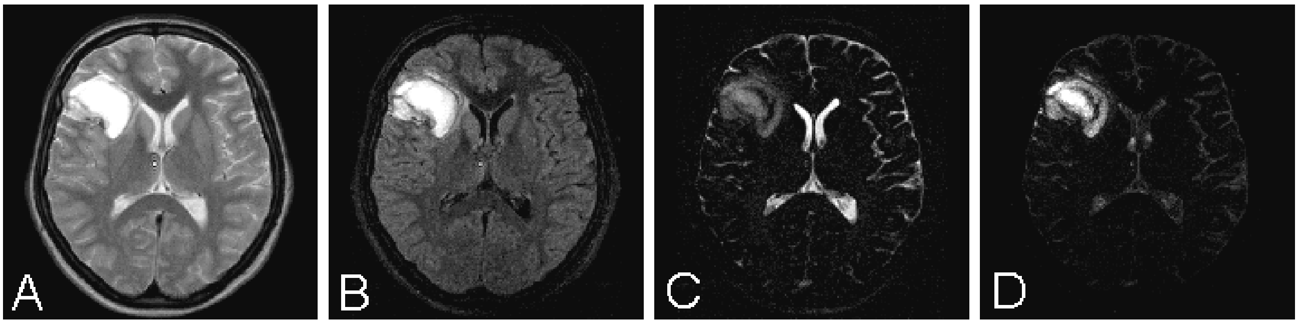

Figure 14: A – T2-WI, B – simultaneous suppression of water and fat signals, C – simultaneous suppression of fat and mucous signals. For three-component suppression, some additional details are revealing in the structure of pathology invisible on the T2-WI and even in the regime with simultaneous suppression of water and fat signals.

5. CONCLUSIONS

Suppression of normal tissue signals is an effective approach for investigation of pathological changes of brain structures. As an ideal solution, homogeneous distribution of normal tissue contrast should be by result of normal tissue signal suppression. Application of simultaneous suppression of water and fat signals is wanted for evenness of normal tissue contrast. In some cases, it is wished to suppress signals from other normal tissues, for example, from mucous.

Simplification of tissue contrast picture allows:

1. To enhance visualization of pathology up to a signal from it will be available to give brightness scale on MR images.

2. To create optimal conditions for measurement of defeat zone volume and 3D- visualization of that zone.

Nowadays it is unclear how to realize multi-component (more 2 components) suppression of normal tissue signals in the context of single MRI scanning providing hereby satisfactory level of useful signal. Therefore combination of experiments with 2-component suppression of signals and arithmetic or logic operations under given MR images is a compromise solution of the problem.

Lowering of common signal level including tissue of interest case is a problem to realize simultaneous suppression of normal tissue signals with help of low-field MRI scanners. Importance of the problem should be decrease by realization of analogous experiments on more high-field scanners. In the same time suppression of strong signals from normal tissues allows to expand dynamic range of receiver that gives possibility to optimize its amplification in conditions of weak signal from interesting site.

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