Using Diffusion-weighted Images to Identify Brain Tumors

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Abstract— The paper presents an evaluation of the magnetic resonance images of a pathology in the human brain. The experiment involved patients with high-grade glioma tumors in the brain, and an MR tomograph operated by the University Hospital Brno-Bohunice was utilized in the related examinations.

In our investigation, we measured images weighted by diffusion. A very interesting technique is diffusion-weighted imaging (DWI), where the measurement sequence comprises a table with 32 vectors of the b-factor orientation. The goal is to perform signal processing in the measured diffusion-weighted images. We proposed a special algorithm for the processing of the DWI image signal. The next step in the procedure was the statistical evaluation of DWI images of healthy and diseased human tissues. We also calculated the brain white matter images, such as those of the fraction anisotropy, RA (relative anisotropy), and VR (volume ratio).

1. INTRODUCTION

The research of pathology of human tissues is currently very interesting [1, 2]. Development of the magnetic resonance imaging represent very significant step because this technique provides images with excellent soft tissues contrast [3, 4]. We used methods for diffusion weighted images (DWI). In this method the pixels are weighted by diffusion coefficients D. This coefficient constitutes a random translational motion of molecules given by their thermal energy without requiring mass volumes motion. During diffusion time [5], the molecules may pass through regions having different diffusion coefficients D, by which means there occurs time dependence of the coefficient The most commonly used method for measurement of diffusion coefficient is The Pulsed Field Gradient Spin Echo (PFGSE). It is Spin echo methods, with two diffusion gradients [6].

Diffusion is often an anisotropic quantity (the D-value differs depending on the direction), and therefore coefficient D turns into tensor $\mathbf{D}$, which can be obtained minimally through measurement in six independent directions. From the tensor $\mathbf{D}$, we can calculate also these diffusion weighted images: Mean of all B0s, Mean of all DWIs, Tensor, Color Map, Anisotropy FA, Anisotropy RA, Anisotropy VR, $K2$, $K3$, $R1$ [5]. The goal of this paper is comparing these methods and finding the best method for diagnosing a tumor in the brain tissue.

2. EXPERIMENT

In our experiment we used a MR tomograph at the University Hospital Bohunice. The MR tomograph dispose of static field flux density $B_0 = 1.5\,\mathrm{T}$. Method of measurement and processing was tested on the patient with tumor in brain area.

We defined the area of tumor, tumor vicinity — edema and healthy tissue. The statistic analysis was made in these selected areas of the tissues. The value of maximum, minimum, means and standard deviation was obtained. With the knowledge of the individual tissues statistical quantities, the particular tissues can be automatically searched by using a special proposed algorithm.

In our experiment we measured diffusion coefficient — anisotropy quantities. We used 32 direction gradient system (better SNR [7–11]), and therefore coefficient D turns into tensor $\mathbf{D}$. From the tensor $\mathbf{D}$, we calculate also these diffusion weighted images: Mean of all B0s, Mean of all DWIs, Tensor, Color Map, Anisotropy FA, Anisotropy RA, Anisotropy VR, $K2$, $K3$, $R1$ [5].

- **Mean of all B0s** — this image is weighted by mean value of all images measured without diffusion gradient pulse.
- **Mean of all DWIs** — image weighted by mean value of all measured DWI images.
- **Tensor** — image weighted by diffusion tensor [5].

- **Color Map** — Color-coded orientation map. In the color-coded map, red, green and blue value represent fibers running along the right-left, anterior-posterior, and superior-inferior axes, respectively are scaled between 0 and 1.
- **Anisotropy FA (Fractional Anisotropy)** — refers to how restricted diffusion is. So anisotropy means "not the same in all directions", which is what we are trying to find out about the diffusion of water molecules in each voxel. The ADC and eADC just communicate information about the diffusion in a voxel, where as anisotropy maps go one step further and communicate information about the orientation of the underlying structure of the fiber tracts in the brain.
- **Anisotropy RA (Relative Anisotropy)** — is similar to FA, but it is a slightly different calculation (like FA it uses the scalar values from the tensor eigenvectors, but never mind about that now). FA gives better detail.
- **Anisotropy VR (Volume Ratio)** — is another calculated measure of anisotropy. The SNR and detail of VR is lower than FA and RA. The one thing VR has going for it is that the

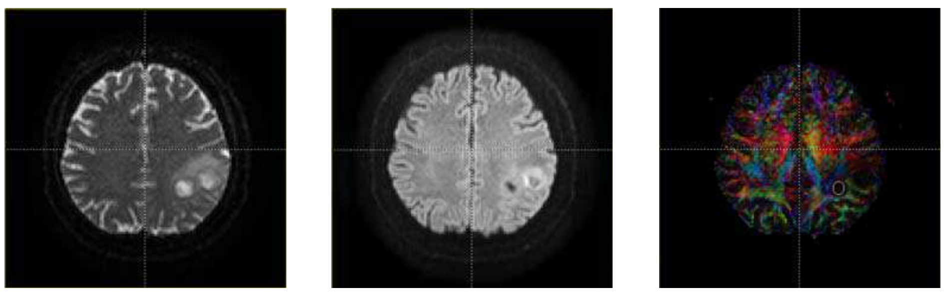

Figure 1: Transversal slices with 2D imaging of the brain with tumor; images from the left hand side: Mean of all B0s, Mean of all DWIs and Color Map.

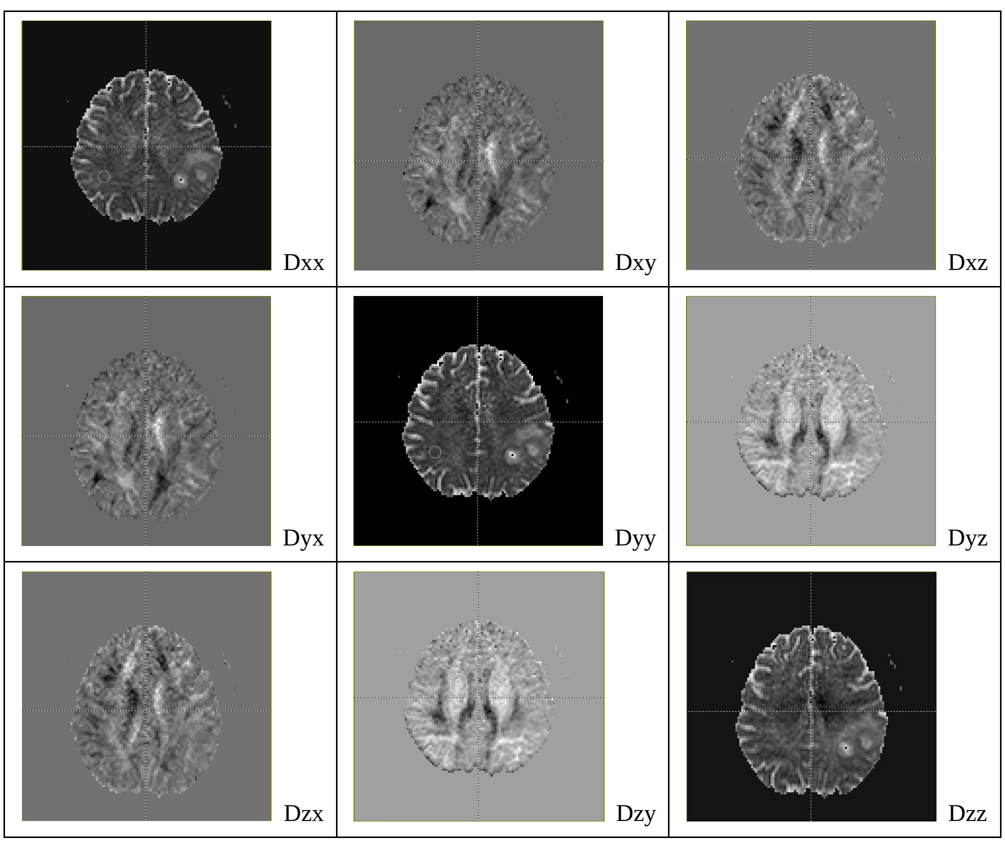

Figure 2: Tensor weighted images of the brain with tumor.

contrast between regions of low and high anisotropy is stronger than FA or RA.

- **K2** — represents the magnitude of anisotropy (by analogy to a polar cylindrical coordinate system $K2$ is the radial component and $K3$ is the azimuthal component)
- **K3** — represents the mode of anisotropy, is defined on interval $[-1, 1]$, where $K3 = 0$ indicates an orthotropic tensor, and $K3 = 1$ indicates a linear anisotropic tensor (one large diffusion tensor eigenvalue and two small eigenvalues).
- **R1** — a mutually orthogonal invariant set containing fractional anisotropy as a member. For symmetric, positive-definite tensor $R1$ is defined on the interval $[0, +\infty]$. $R1$ is a measure of tensor magnitude.

3. RESULTS

First we obtained 32 images of each slice. In a next step we processed these images and calculated different types od diffusion weighted images, as you can see in Figure 1–Figure 3. Figure 1 shows three measured images (Mean of all B0s, Mean of all DWIs and Color Map) of brain with tumor.

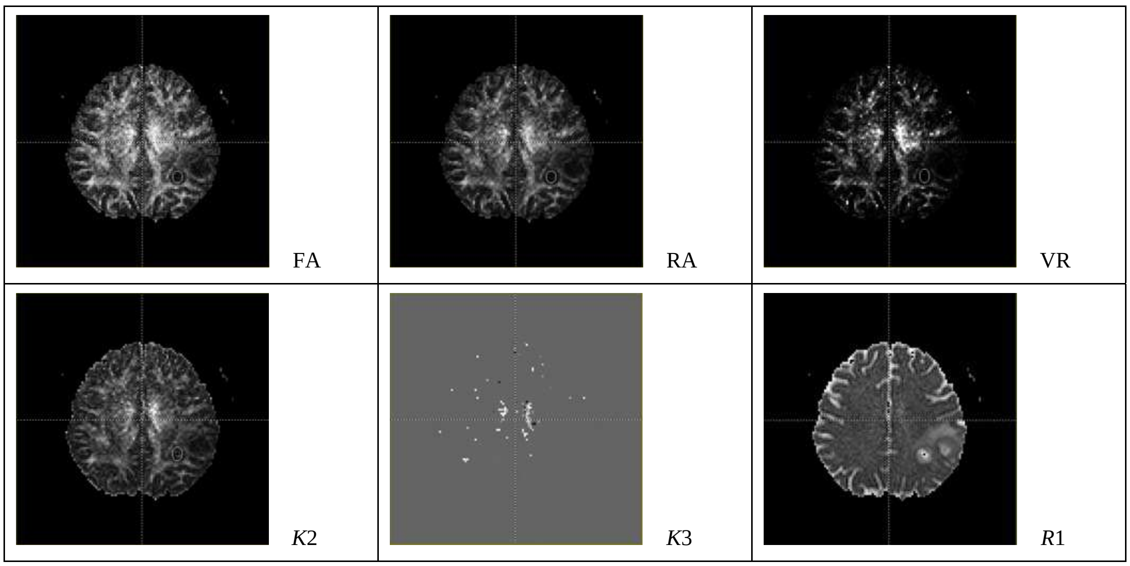

Figure 3: Images weighted of FA, RA, VR, $K2$, $K3$ and $R1$.

Table 1: The evaluate parameters from multi-contrast images.

Contrast	Tumor		Edem		Healthy tissue	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
Mean DWIs	23.47	6.88	25.60	1.52	24.70	1.69
Mean B0s	**144.52**	**22.74**	**108.34**	**4.17**	**53.00**	**5.51**
Tenzor_Dxx	1.84e-003	5.88e-004	1.66e-003	1.31e-004	1.98e-004	8.81e-004
Tenzor_Dyy	1.75e-003	5.78e-004	1.44e-003	1.32e-004	8.32e-004	1.35e-004
Tenzor_Dzz	1.77e-003	5.30e-004	1.31e-003	1.10e-004	6.74e-004	2.13e-004
Tenzor_Dxz	1.11e-005	5.62e-005	8.57e-005	6.64e-005	−1.53e-005	8.68e-005
Tenzor_Dxy	−3.56e-005	6.98e-005	4.44e-006	1.07e-004	3.01e-005	1.10e-004
Tenzor_Dyz	−1.73e-005	5.36e-005	1.27e-005	6.28e-005	−5.10e-005	1.66e-004
Color Map	-	-	-	-	-	-
FA	0.09	0.04	0.17	0.05	0.36	0.10
RA	0.07	0.03	0.14	0.04	0.32	0.10
VR	9.90e-003	8.70e-003	0.03	0.02	0.16	0.11
$K2$	2.36e-004	1.11e-004	3.61e-004	1.14e-004	4.23e-004	1.08e-004
$K3$	2.36e-004	1.11e-004	3.61e-004	1.14e-004	4.23e-004	1.08e-004
R1	**3.11e-003**	**9.63e-004**	**2.57e-003**	**1.45e-004**	**1.45e-003**	**1.83e-004**

Figure 2 displays individual diffusion weighted images from which it is possible to calculate the diffusion tensor weighted image.

Figure 3 shows images weighted of Fractional Anisotropy — FA, Relative anisotropy — RA, Volume Ratio — VR, and $K2$, $K3$ and $R1$. The evaluated statistical parameters of measured and processed images are shown in Table 1.

4. CONCLUSIONS

This work is focused on the measurement of diffusion-weighted imaging (DWI), where the measurement sequence comprises a table with 32 vectors of the b-factor orientation. The goal is to perform signal processing in the measured diffusion-weighted images of brain tumors. We proposed a special algorithm for the processing of the DWI image signal. The next step in the procedure was the statistical evaluation of DWI images of healthy and diseased human tissues. We also calculated the brain white matter images, such as those of the fraction anisotropy, RA (relative anisotropy), and VR (volume ratio).

To the classification and segmentation of tissues are very interesting obtained data from MeanB0s and R1 weighted images. The values in Table 1 are very important for selection of segmentation methods such as thresholding, edge analysis by Sobel mask, watershed and very interesting method based on region-based level set approach or active contour [12]. The segmentation can play an important role in determining pathology in animal tissues even in human tissues.

ACKNOWLEDGMENT

This work was supported in part by the Grant GAČR 102/12/1104 and the programme FEKT-S-14-2545 and Education for Competitiveness Operative Programme CZ.1.07.2.3.00.20.0175 (Electro-researcher).

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