Segmentation of Brain Tumor Boundaries using Pattern Recognition of Magnetic Resonance Spectroscopy

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Introduction MRI has been utilized to differentiate the anatomical and morphological features of tumors, but is not specific to heterogeneous features. MR spectroscopy (MRS) has been used to characterize tumors based on measurement of metabolite concentration or ratio and has been suggested to differentiate normal brain, tumor type and therapy induced changes (1-4). Yet, partial volume effects and other variations confound definition of tumor features and specifically in the boundaries between features. In this work we employed a linear transformation to segment partial volume effects of known spectral patterns from each voxel in order to determine if boundaries of tumor components could be defined.

Acquisition MRS from 10 patients with biopsy confirmed low- and high-grade glioma were acquired at 1.5T (GE, Milwaukee, WI) using a 4-slice spin echo sequence (TR/TE - 2300/272ms) that included water and octagonal outer volume saturation pulses, 24cm FOV, 32x32 phase encoding and 15mm sections. Images of the peak area for each major spectral metabolite, i.e. choline, creatine, N-acetyl aspartate, and Lactate were reconstructed after field homogeneity correction. In addition, T2- and T1-weighted MRI were acquired for comparison.

Methods The linear transformation was the Eigenimage filter (EF) (5,6). The EF produces a composite signal from a weighted summation of the received signal. The EF has been shown to correct for partial volume averaging effects providing differentiation of overlapping patterns in MRI. In this application spectral patterns are separated and the partial volume in each voxel is mapped allowing the boundaries between these patterns to be determined.

Steps used in the analysis:

1. A region of interest (ROI) is created to define normal tissue spectrum.
2. The EF is used to remove the normal spectral pattern from each voxel. The pixel value in resultant image (Figure 1 - Initial Segmentation) is proportional to the amount of "abnormal" spectral features within each voxel.
3. Initial Segmentation image is used to define a ROI from the voxel displaying the maximum dissimilarity from normal tissue (i.e. "hot" voxel). The spectral pattern from this voxel and normal tissue are used in EF. The pixel values in the resultant image are proportional to the amount of any additional spectral patterns that remain within each voxel after normal and the "hot" voxel spectral patterns are removed (Figure 1 - 2nd Segmentation image).
4. ROI defined for "hot" voxel from 2nd Segmentation image and used as additional spectra in EF. This procedure is repeated until the resultant image (Figure 1 - Final Segmentation image) displays only noise. This defines all normal and abnormal spectral patterns.
5. EF used to create a separate image (Figure 1 - Feature images) defining extent of each spectral pattern. In the Feature images partial volume of each spectra are separated.
6. Boundary for each feature is determined by thresholding the corresponding Feature image at 99% confidence level for removing other features (i.e. removing background).

Low Grade Glioma

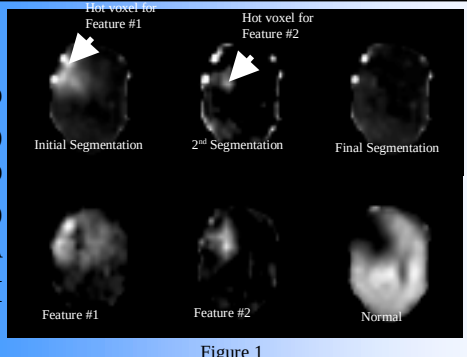

Figure 1

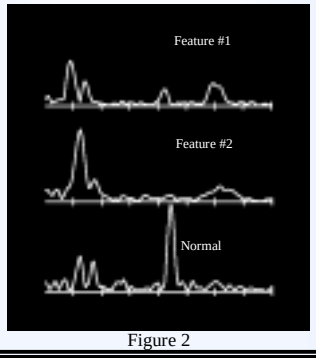

Figure 2

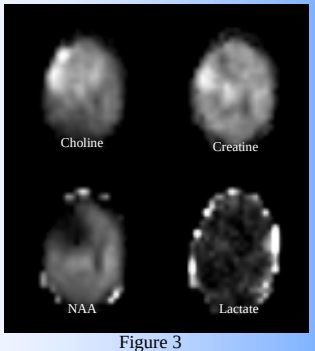

Figure 3

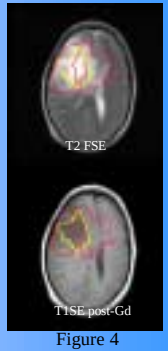

Figure 4

High Grade Glioma

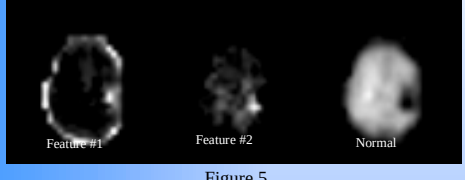

Figure 5

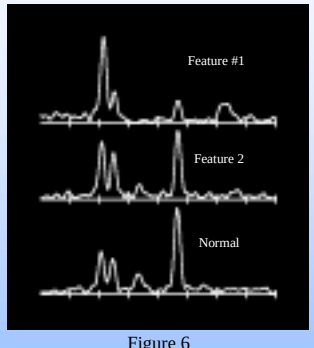

Figure 6

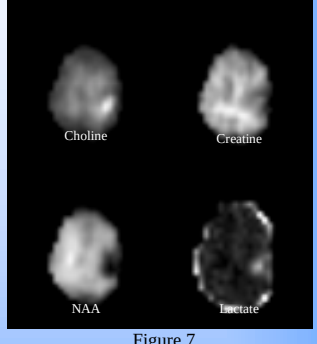

Figure 7

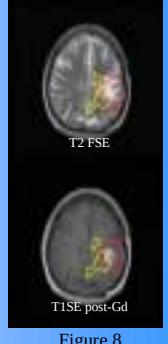

Figure 8

Results The method segmented normal and abnormal spectral patterns in all studies. This is shown in example cases in Figures 1-8. In Figure 1 the methodology is demonstrated and resultant Feature images for a low grade glioma are shown. In this study 2 abnormal spectral patterns were found (Figure 2). The spectrum from each feature varied from normal in the presence lactate, loss of NAA, and elevated choline. The variation between features is seen mainly in the amount of lactate and choline present and in Feature #2 NAA is present. Peak images (Figure 3) showed variable signal distribution throughout the brain, although the definition of lesion boundaries is not clear. The boundary from each Feature image is shown overlaid on the MRI in Figure 4. Feature #2 (yellow outline) is seen as the core of the lesion and Feature #1 (red outline) corresponds to the surrounding T2 hyper-intensity. The second example is from a high grade study and again 2 spectral patterns were found (Figures 5-8). Spectral patterns in this case showed lactate present in Feature #1, reduced NAA and elevated choline. Feature #2 showed no lactate and increase choline and creatine. The lesion is again visible in the peak image but the extent is still uncertain (Figure 7). The boundary from the Feature images (Figure 8) showed Feature #1 (red outline) to be larger than Gd enhancement and similar to the T2 hyper-intensity. Feature #2 (yellow outline) extended out from Feature #1 and beyond the T2 hyper-intensity. Note in Figure 5 Feature #2 may be interpreted as extending away from the lesion throughout the brain. The boundary shown on Figure 8 is not entire brain due to 99% confidence level used for removing background.

Discussion We have shown that EF can separate differing spectral patterns within a tumor and define a map of these features that can be used to determine their boundary. The differences in the spectral patterns segmented are clearly due in part to partial volume effects within the voxels. Since the varying intensity in the Feature images is proportional to the partial volumes the boundaries defined may extend farther than the areas seen on the peak images (see Figure 5). In addition, the determination of the feature boundaries can utilize standard statistical methodologies based on the EF transformation and partial volume within voxels can be inferred. This is seen in the example low grade study (Figure 4) where Feature #2 corresponds to the T1 hypo- and T2 hyper-intensity region of the lesion. This boundary may be the edge between tumor infiltration and edema. The determination if these different regions or spectral characteristics can classify tumor pathology is underway using image directed biopsy.