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A New Method of Analysis of Brain MRI Images for Quantitative Grading of Brain Tissue Pathology

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Abstract. Studies were performed on a set of magnetic resonance images (MRI) of the human brain (in the axial plane) to find the relationship between the light intensity high frequency power (HFP) values and the degree of pathology of the brain tissue (infarct and tumor). Analysis of the results show that the differences in the light intensity HFP values in the MRI images for subjects with brain tissue pathology compared to the normal subjects, were highly significant ($p < 0.05$) in the areas of the brain where there was a high incidence of pathology. The increase in the light intensity HFP values for the subjects with infarcts and tumors are in the range of (18.01 – 267.10) times and (10.57 – 80.08) times, respectively, compared to normal subjects. The results show that the quantitative changes in the parameter value can be assessed in grading the different levels of brain tissue pathology, to assist the neuro surgeons for early corrective methods so as to protect these patients from further damage to their brain tissue.

Keywords: brain tissue pathology, diffusion weighted imaging, high frequency power, infarct, MRI images, tumor, quantitative grading.

1. Introduction

MRI is a promising tool that is being increasingly used in the diagnosis and management of a wide variety of clinical applications. There is a great deal of research oriented in the clinical applications of MRI applied to the field of neurology [1]. Diffusion Weighted Imaging (DWI), a modification of regular MRI techniques, is extensively being used to study the anatomy of the brain and has been an important area of study in the past decade [2]. The applications of DWI in neuroradiology are increasingly widespread, chiefly in ischemic strokes, tumors, infectious, degenerative, traumatic, and inflammatory brain pathologies. DWI has been applied to classify various types of brain pathologies, diagnose brain infarcts and tumors, grade brain tumors, detect and assess strokes, and so on [3, 4]. Most of the work carried out using DWI, employs comparative analysis using Apparent Diffusion Coefficient (ADC) values and image segmentation schemes to realize the required purpose [5].

The present work employs DWI of the brain and is directed towards differentiating and grading the brain pathologies namely infarcts and tumors using the light intensity HFP value as the parameter. Mainly an effort is made to grade the changes in the above parameter compared to the normal, so that early stages of changes taking place in the brain can be detected. The main advantage of the method is that the quantitative changes in the parameter value can be assessed resulting in the different grades of pathology and this can help for the early detection of the brain disorders, which is very crucial in the field of pathology, since therapies and medicines are usually most effective while a disease remains in its premature stage.

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2. Methods

In DWI, each image voxel has an image intensity that reflects a single best measurement of the rate of water diffusion at that location. The rate of water diffusion in all the tissues is a direct function of its physiological state, and impacted by diseases such as infarcts and tumors. DWI makes it to visualize and measure these rates of diffusion by producing increased restriction of water mobility and hence a bright imaging appearance due to high signal intensity in the area of pathology [6]. Consequently the spatial intensity variation distribution for an abnormal scan has abrupt jumps compared to that of a normal scan in the region where the brain tissue pathology is observed. The power spectrum of the brain scan intensity image might therefore result in higher value of the HFP component in the affected region of the abnormal scan when compared to the normal scan. The relative light intensity HFP values can be quantified across different pathological subjects and can work as an indicator in diagnosing and differentiating pathological tissues from normal tissues and can also lead in aiding early detection of brain pathologies.

2.1. Algorithm

For the purpose of our study a normal brain scan means one with no pathology and no surgical history. The study is carried out on the DW MRI images of the brain (in the axial plane) for pathological and normal subjects. The pathologies addressed are primarily brain infarcts and tumors. DW MRI images of the brain in the axial plane are obtained using a 1.5 T MRI machine. These diffusion images obtained in DICOM format are converted to bmp format with intensities scaled to fit the conventional range of 0-255. This is done to reduce the complexity in the image manipulation algorithms and for speedup in processing images.

Each brain MRI scan obtained is divided into six anatomically significant areas as shown in Fig. 1. The size of the individual DW MRI images varies depending on different individuals. For every subject we have a set of diffusion images in the axial plane taken at different levels that represent the respective slices (say from 1-19). The subject with brain tissue pathology will have some abnormality indicated in one of the six areas in the respective slices depending on the kind of pathology as opposed to a normal subject where there will not be any abnormality seen in any of the areas for all the slices. The axial slices of the pathology case that indicate abnormality are selected for image analysis. To carry out a comparative study, the slices at the same level as pathology are selected from the normal subject. Analysis is carried out simultaneously across the slices for the pathological and normal subjects.

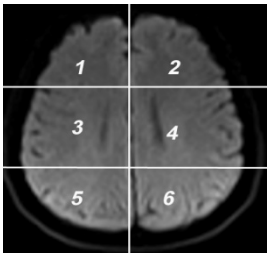


Fig. 1: Axial DW MRI with areas.

The region corresponding to the pathology, I(x, y), is identified in each slice (as a region of abrupt intensity changes). The equivalent region is chosen from the normal subject for comparison. The region, I(x, y,) is divided into smaller sub-regions, f(x, y). Each particular sub-region of the brain, f(x, y), corresponding to an image size is represented by (M x N) pixels. The Fourier spectrum, F(u, v), of each sub-region, f(x, y), is evaluated and the spatial frequencies and their distribution for these regions are analyzed by performing the two-dimensional Discrete Fourier Transform (DFT) using MATLAB version 7.7. The spatial frequencies (u and v) are denoted by cycles per pixel since the image size (distance) for the analysis is given in terms of pixels. Using the periodicity property of DFT [7], the Fourier spectrum is shifted to the center of frequency plane. The DC component, F(0, 0) is deleted since it gives only the average value of the image intensity. The power spectrum is obtained by squaring the magnitudes of the Fourier spectrum light intensity variations [8, 9] of the brain images and the total power, TP, in an image is obtained using equation (1). Since for the sub-regions of the brain, f(x, y), M and N are different (depend on the size of the particular sub-region), the cut-off frequency, D_0 (in cycles per pixel), which separates the lower and higher spatial frequency components, is defined by equation (2).

$$TP = \left\{ \sum_{u=-\frac{M}{2}}^{\frac{M}{2}} \sum_{v=-\frac{N}{2}}^{\frac{N}{2}} |F(u,v)|^2 \right\} - |F(0,0)|^2 \quad (1)$$

$$D_0 = \begin{cases} \frac{M}{4} & if\ N \geq M \\ \frac{N}{4} & if\ N < M \end{cases} \quad (2)$$

D (u, v) is the distance from the point (u, v) to the origin of the frequency plane, defined by equation (3)

$$D(u,v) = \sqrt{u^2 + v^2} \quad (3)$$

The low frequency power (LFP) and HFP are calculated using equations (4) and (5) respectively.

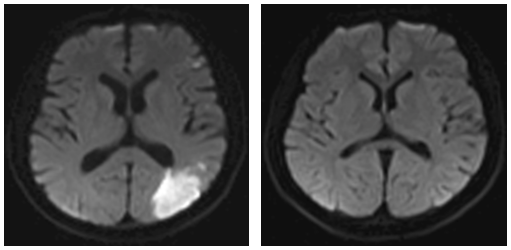
$$LFP = \left\{ \sum_{D(u,v)=0}^{D_0} |F(u,v)|^2 \right\} - |F(0,0)|^2 \quad (4)$$

$$HFP = TP - LFP \quad (5)$$

For each sub-region, f(x, y), corresponding to the pathological and normal subject, the magnitude and location of the light intensity HFP value is obtained. The overall maximum light intensity HFP value for the pathological subject across the sub-regions is chosen as the resultant HFP parameter for that particular slice. The corresponding light intensity HFP value from the normal subject is noted for comparison. The value of this resultant light intensity HFP obtained from pathological subject indicates whether there is any sudden change in the intensity level in any of the sub-regions of that slice and if there is then we can readily establish the sub-region and also the exact location ((x, y) co-ordinates) within that sub-region. Finally the mean value of the resultant light intensity HFP across all the slices is obtained for each pathological and normal subject.

3. Result

The DW MRI of a subject showing infarct in area 6 and at slice level 12 is shown in Fig. 2 (a). Fig. 2 (b) shows the DW MRI at the same slice level for the normal subject. The region in area 6 that shows the infarct is selected for analysis and the equivalent region is selected from the normal subject [10]. This region is further divided uniformly into smaller sub-regions.



(a) (b)

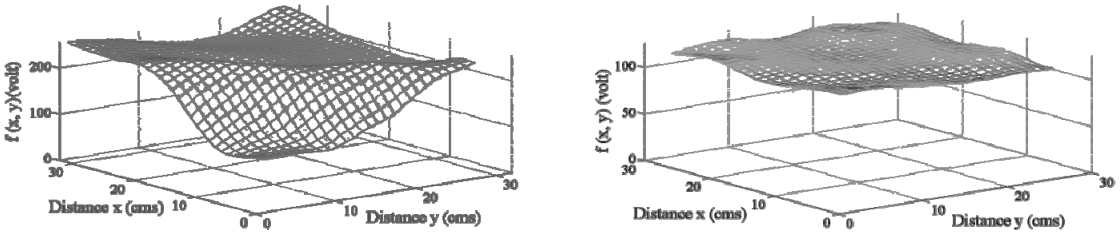
Fig. 2: (a) Axial DW MRI showing infarct in area 6

(b) Axial DW MRI of normal subject

For each sub-region in the infarct we evaluate the value for the light intensity HFP and at the same time note the corresponding values of the light intensity HFP for the normal subject. Finally the resultant HFP is the highest of all the light intensity HFP values evaluated across the sub-regions. Fig. 3 (a) shows the spatial variation of intensity distribution for that sub-region (size 30 pixel x 30 pixel) in area 6 (slice level 12), where there is highest HFP value (94.30) observed for the subject with infarct. The spatial variation of intensity distribution for the corresponding sub-region (30 pixel x 30 pixel) for the normal subject is shown in Fig.3 (b). It is observed that the spatial intensity variation distribution for subject with infarct has abrupt jumps with higher intensity variations compared to normal subject. Therefore the value for the highest HFP

(94.30) for the infarct subject is much higher when compared to that for the normal subject (0.41). The highest value of the HFP parameter evaluated indicates the maximum change in the light intensity variation across the selected region in slice level 12 for the infarct subject and also indicates its exact location, (23, 15), in the (x, y) co-ordinates. The values obtained for HFP from the infarct and normal subject are compared for quantitative analysis. This procedure is carried out across all the slices selected for the infarct and normal subject. Finally the mean value of the highest HFP across all the slices is taken as decisive HFP parameter.

Image size = (30x30) pixels Pixel size = (0.04x0.04) cm



(a) (b)

Fig. 3: (a) Image intensity distribution for infarct subject in area 6
(b) Image intensity distribution for normal subject in area 6

For the purpose of our study we have considered the DW MRIs of 16 subjects for infarcts with mean age 62.18(±15.51) (two subjects in area 1, one subject in area 2, four subjects in area 3, three subjects in area 4, two subjects in area 5 and four subjects in area 6), 9 subjects for tumors with mean age 58.88(±20.24) (three subjects in area 1, two subjects in area 2, one subject in area 3, one subject in area 5 and two subjects in area 6) and compared each pathological subject with the corresponding DW MRI of the normal subjects with mean age 60.92(±16.90). For each pathological subject we have a set of highest light intensity HFP values at each slice level and the mean of these highest light intensity HFP values across all the slices. As a result we have a single decisive light intensity HFP parameter value for the pathological subject and the corresponding HFP value for the normal subject.

Table 1 & 2 represent the mean values of the highest light intensity HFP across all the slices for the subject with brain infarct and tumor and the corresponding HFP values for the normal subject, respectively. Statistical student t-test was performed at 95% confidence level to compare the mean variations of HFP values of the normal and pathological (infarct and tumor) subjects. It is found that the mean values of HFP for the pathological subjects when compared to normal vary significantly ($p < 0.05$) in the area of pathology. The plot of the variation in the mean value of the highest light intensity HFP across the subjects with infarcts and tumors, when compared to normal is shown in Fig. 4 & Fig. 5 respectively.

Table 1: Mean values of highest light intensity HFP for normal and infarct subjects

Subject	Normal	Infarct	Relative change from normal
	Mean value of maximum light intensity HFP		
I1	1.05	102.53	93.23
I2	1.02	97.03	101.67
I3	0.76	90.97	178.25
I4	0.73	119.47	159.98
I5	0.89	109.90	127.12
I6	0.65	131.59	267.10
I7	0.35	24.51	69.83
I8	0.56	93.17	167.92
I9	0.60	130.65	261.59
I10	0.52	44.20	83.66
I11	2.23	114.60	65.40
I12	1.55	31.46	18.01
I13	0.68	42.63	62.50
I14	1.60	46.81	28.33
I15	0.54	15.56	27.88
I16	0.83	67.25	80.39

Table 2: Mean values of highest light intensity HFP for normal and tumor subjects

Subject	Normal	Tumor	Relative change from normal
	Mean value of maximum light intensity HFP		
T1	1.00	43.92	77.50
T2	0.40	20.81	50.26
T3	0.27	21.57	80.08
T4	0.69	16.57	26.10
T5	0.76	12.69	23.32
T6	0.70	16.84	28.97
T7	0.24	15.59	63.37
T8	0.92	10.05	10.57
T9	0.66	27.79	40.78

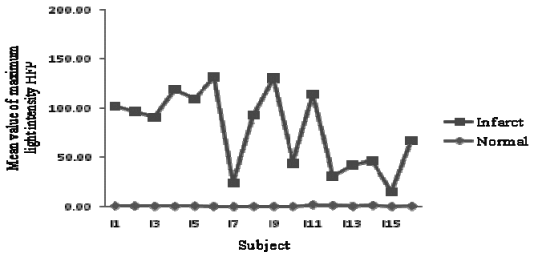


Fig. 4: Variation in the mean value of the maximum light intensity HFP for infarct and normal subjects

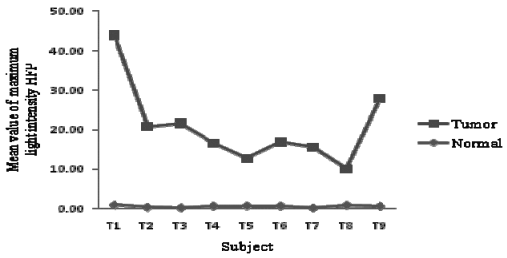


Fig. 5: Variation in the mean value of the maximum light intensity HFP for tumor and normal subjects

It is observed from Table 1 and 2 that the increase in the mean value of highest light intensity HFP for the subjects with infarcts and tumors is in the range of (18.01 – 267.10) times and (10.57 – 80.08) times, respectively, compared to normal subjects. Presently we are carrying out analysis using a higher number of pathological subjects to obtain data quantification that will aid in deciding the very early stages of the brain tissue pathologies.

4. Conclusion

Analysis of the results on subjects with infarcts and tumors indicate that the values of the light intensity HFP parameter can be used to markedly distinguish the pathological subjects from the normal subjects. The increase in the mean value of the highest light intensity HFP from (18.01 – 267.10) times for infarct and (10.57 – 80.08) times for tumor, when compared to normal, shows that the quantitative changes in the parameter values can be assessed and used to grade the pathologies so that early stages of the changes taking place in the brain can be detected. This can positively aid the neurosurgeons to take immediate remedial steps or to consider early corrective methods to protect the subjects from any further damage to their brain tissue.

5. References

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